The Neurocognition of *Dance*

Mind, Movement and Motor Skills

edited by
Bettina Bläsing,
Martin Puttke
and Thomas Schack

The Neurocognition of Dance

Dance has always been an important aspect of all human cultures, and the study of human movement and action has become a topic of increasing relevance over the last decade, bringing dance into the focus of the cognitive sciences. This book discusses the wide range of interrelations between body postures and body movements as conceptualised in dance with perception, mental processing and action planning.

The volume brings together cognitive scientists, psychologists, neuroscientists, choreographers, and ballet teachers, to discuss important issues regarding dance and cognition. First, scientists introduce ideas that offer different perspectives on human movement. Professionals from the world of dance then go on to report how their creative and pedagogical work relates to cognition and learning. Finally, researchers with personal links to the dance world demonstrate how neurocognitive methods are applied to studying different aspects related to dance.

This book is suitable for students and professionals from the fields of neuropsychology, cognitive psychology, sport psychology and sport science, movement science, motor control and development, kinesiology, cognitive robotics dance, choreography, dance education and therapy.

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Foreword

A joint interest of dance and embodied cognitive science is to understand movement and action. Dancers have to learn highly complex movement sequences; they need to understand why and how they move, to cognitively grasp the structure of movement, in order to maximize their performance. A dancer's skill thus includes not only physical abilities but also a wide range of cognitive skills pertaining to controlling a body in a physical environment. How movement and action emerge, how they are perceived, mentally represented and planned, are also focal research questions in biomechanics, sports and the cognitive sciences in general. These questions regard the human mind and the many ways it relates to the body, for instance, how the brain's sensory-motor system is involved in perceiving and conceptualizing movement. A more profound understanding of such issues may also come to bear in dance instruction.

Emanating from an intense workshop convention at Bielefeld University's Centre for Interdisciplinary Research (ZiF – Zentrum für Interdisziplinäre Forschung) in late October 2007, this book presents a collection of studies and perspectives related to the cognitive science of dance. Bringing together dance professionals and leading scientists from the cognitive and movement sciences, this convention was at the same time inspiring and unusual, as here disciplines encountered each other, which at first sight did not seem to have much in common. But soon it became apparent that there were a lot of things to be exchanged.

The atmosphere of departure that marks the work presented in the present book derives to a great extent from the impressions shared by the contributors that problems and approaches are brought together which may give rise to a fruitful new line of research. Dance, coming to the focus of the cognitive sciences only recently, turns out to be a fascinating area of study. For practitioners, the scientific examination of their area of practice may contribute to supporting and extending their experience, both in performance and in instruction.

It is hoped that this book will become a pioneering contribution and a lasting reference in an exciting new field of scientific endeavour. As managing director of the ZiF I would be glad if the atmosphere of our institute has been inspiring in this embarkment.

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January 2009

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Bettina Bläsing, Martin Puttke and Thomas Schack, August 2009

Introduction

Towards a neurocognitive science of dance – two worlds approaching or two approaches to the same world of movement?

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What will happen when dancers, choreographers, cognitive and neuroscientists come together to talk about movement, the body and the brain in order to understand the phenomenon of dance? We were intrigued by this question when we organised the symposium that finally led to the production of this book. What we witnessed during these 3 days truly exceeded our expectations. We were impressed by the positive personal reactions by members of the scientific community, who, in several situations, were simply amazed and touched by the mere beauty, precision and energy of movement of the dancers who improvised or demonstrated their movement sequences in the lecture hall. Dancers and dance teachers were equally as fascinated when they discovered that many of the theoretical ideas and results that were brought forward in the talks also yielded beauty and precision, and often also practical benefit for the dance community. The reactions on both sides expressed silent respectful amazement, which may be the premise for a true gain of knowledge, the origin of mutual understanding. It might have been this personal experience of feeling deeply touched that keeps bringing the newly established community of dancers and scientists together and that has given rise to the idea of writing this book together.

One motivation for this project certainly is an emotional one, as the chapter titles chosen by some of the authors suggest. Another motivation lies in the shared view that important insight into the nature of human movement and action has been gained over the last decade, and that this insight has to be communicated and discussed beyond the borders of professional communities. Dance has always been an important aspect of human cultures, and bringing dance into the focus of the cognitive sciences will certainly broaden our understanding of the nature of human minds and brains.

Since the cognitive sciences have discovered the importance of embodiment, of the concept of minds being grounded in the physical environment in which they have evolved and with which they constantly interact (see Wilson, 2002), movement of the human body has become a topic of increasing relevance. Questions of how human body movement is controlled and how special movements are learnt concern not only scientists interested in muscle physiology and biomechanics, but also those trying to understand how thinking, reasoning and learning are processed by the human brain. Experimental psychology has discovered a wide range of interrelations of body postures and body movements with perception, mental processing and action planning (e.g., Hoffmann, Stoecker, & Kunde, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Koch, Keller, & Prinz, 2004; for an overview see Schack & Tenenbaum, 2004a, 2004b), for example in paradigms like the Simon effect (Simon & Rudell, 1967) or mental rotation tasks (e.g., Shepard & Metzler, 1971; Parsons, 1987; Jola & Mast, 2005).

Only a little more than a decade ago, scientists in Parma, Italy, discovered the so-called mirror neurons in the monkey brain – neurons that fire during performance of a specific action as well as during observation of that same action performed by others (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). This discovery and the subsequently arising interest in the principles of a neurocognitive mirror system in the human brain have initiated an extensive shift within the neurosciences, in a close cooperation with experimental psychology, towards research related to the coupling of neural codes for action observation and action execution (e.g., Arbib, 2002; Iacoboni, 2008). This field of research investigates general principles of the interplay between perception, cognition and action in humans (e.g., Schütz-Bosbach & Prinz, 2007). It offers a new understanding of the cognitive basis of model learning (see Bandura, 1986), based on a better description of the human action observation system (Cross, Hamilton, & Grafton, 2006).

What happens in our brain when we observe someone performing a simple task, or a complex movement sequence? What does it mean to “understand” an action, or a movement, as such, and how does this relate to language? Why do we have the ability to imitate the actions of others, and how does this help us to learn? How do we understand what our interlocutor feels, or expresses, by watching his facial expression, gesture, movement quality, and body posture? And how do we apply this mutual understanding in a social context in real time to interact successfully with each other, to join into others’ actions, to compete or collaborate, and to communicate?

When we think about learning and performing complex movements, probably in interaction with others, sooner or later, dance comes to mind. A dancer's skill includes not only expert physical abilities but also a wide range of cognitive skills – which again might reflect how closely related these domains are when it comes to human body movement. Dancers often have to learn highly complex "designed" movement sequences combined in choreographies that might last for hours. They have to be able to perform their part not only perfectly, reproducing the movements without variation, but also with adequate expressive quality, no matter how nervous, tired or exhausted they are, seemingly independent of their own emotional state. While dancing, they constantly have to keep track of their surroundings, space and objects, partners and co-dancers, dynamical qualities of the music, and their audience. While learning movement sequences during the training or during rehearsals for choreographies, they have to be able to immediately transfer steps from one side of the body to the other side or from the forward to the backward direction, as well as from one direction in space to another, without losing orientation. Choreographers rely on these skills and apply them to create and develop the pictures and scenes they have in their mind, to convey the stories they want to tell, to arouse the intended emotional reactions in the audience. Many of the concepts and ideas that are now in the focus of cognitive research have implicitly been in the minds of dancers and choreographers for a long time, yet without deeper scientific understanding of brain functions or cognitive processing. The interest the dance world takes in the neuroscientific side of their art is equally as young as the interest cognitive and brain scientists take in embodiment, the situatedness of the human mind in the physical world and related questions of human body movement. Yet, a mutual fascination has grown during recent years (see, e.g., Stevens, 2005 for an interdisciplinary approach to choreographic cognition).

A few psychologists and neuroscientists have started to work with dancers to find out if and how their highly specialised expert training may have enhanced or modified their cognitive abilities; how their brains integrate all the necessary information while they perform highly sophisticated physical tasks, lined up in hour-long choreographies, that have to be flawlessly remembered, at the same time producing expressions of a deep emotional quality that have the power to captivate the audience (e.g., Bläsing, Tenenbaum, & Schack, 2009; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross et al., 2006; Jola, Davies, & Haggard, 2009; Jola & Mast, 2005). Some of these scientists also have followed a career in dance or choreography themselves, which makes them even more qualified to explain and integrate the most relevant, most promising aspects of both worlds.

Questions and ideas that derive from the interconnection of complex movements and related cognitive processing are not only of interest when regarding high-level professional classical or modern dance and choreography. Pre-school and primary school teachers increasingly apply movement and movement learning as tools, as vehicles for learning in general, even of abstract principles in maths or grammar. They come to the conclusion that children who are allowed to run, jump and dance become more motivated, better learners, and that movement sometimes can teach children more about geometry and dynamics than images and words can. Learning to move in different ways, with different pace and qualities, to express feelings with the body, to interact with space, rhythm, sound and with each other allows children and adults to grow more self-confident and courageous. Learning to dance on a professional level, and learning to teach others how to dance, can be a great challenge and gratification for body and mind. A professional career in dance, however, can also become a thorny path if the teaching methods applied diverge too far from the basic physical, neural and cognitive principles of human motor learning. Therefore, one of the aims of this book is to offer new scientific perspectives on the *neurocognition of dance*, and to give the impetus to integrate scientific knowledge and principles into the way of teaching dance.

When we started our cooperation between the Neurocognition and Action – Biomechanics research group of the Department of Psychology and Sport Science at the University of Bielefeld and the aalto ballett theater Essen 2 years ago, our common goal was to study mental representations underlying movements from classical dance and, based on these studies, to develop improved teaching methods. Within minutes of our first meeting, we already found ourselves discussing questions that went far beyond dance training and sport science, questions of the human mind and the many ways it relates to dance. How are dance sequences created from moving images in the choreographer's mind? How are they processed and embodied by the dancer and communicated to the observer in the audience? What happens in the brain of that observer, and what role does his or her own dance experience play? What does that tell us about movement learning in general and especially about teaching dance? From this discussion, it was only a short step to the idea of organising a brain pool meeting of professionals interested in the above topics.

In October 2007, we had the opportunity to arrange a meeting that brought together dancers, choreographers, dance teachers and leading scientists from the fields of neuroscience, psychology, cognitive and movement science, providing a platform for mutual introductions into each others' disciplines and approaches to thinking, learning and movement. The Werkwoche [Workshop] "Intelligence and Action – Dance in the Focus of Cognitive Science" took place at the Centre for Interdisciplinary Research (ZiF) at Bielefeld, Germany, and was hosted by *Tanzplan Essen 2010* (*Tanzplan Essen 2010* is supported by *Tanzplan Deutschland*, an initiative of *The Federal Cultural Foundation*, Kulturstiftung des Bundes, Germany). The Werkwoche was one of the most inspiring and broad minded conferences many of us had ever encountered, and it left us with the impression that the innovative combination of scientific talks, dance performance, choreographic workshop, lecture demonstration and other topics we had immersed ourselves in during these 3 days had been like jigsaw pieces, diverse at first sight but fitting together beautifully at second, revealing promising parts of an impressive whole picture.

With the publication of this book, we want to share our ideas and insights with a broader audience, with professionals from the worlds of dance and science, with teachers, trainers, therapists, and with everyone interested in dance and cognition. We hope to initiate a process of mutual exchange and stimulation between dancers and cognitive scientists, psychologists and choreographers, ballet teachers and neurobiologists, and we hope that this process might lead to a deeper understanding of dance as movement of the human body and mind.

This book is addressed to a diverse audience, to those readers who are used to digging into scientific theory as well as to those whose work consists of creating, performing or teaching movement. We know that the aim to make this book equally informative and enjoyable for all of them must be a challenge. We have therefore structured the content of our book in such a way that chapters written from similar perspectives are grouped together, in order to provide our readers with a line of orientation. First, scientists introduce ideas that offer different perspectives on human movement and therefore can be applied to dance. Second, professionals from the world of dance have their say, reporting how their creative and pedagogical work relates to cognition and learning. Finally, researchers with personal links to the dance world demonstrate how neurocognitive methods are applied to studying different aspects related to dance.

In Part I of the book (*The science perspective*), we present basic approaches to movement control, providing different perspectives on the way movements are initiated, adapted and stored in memory. The contents of these chapters range from theoretical foundations over experimental studies to computer simulation models. Thomas Schack (*Building blocks and architecture of dance*; Chapter 1) introduces his cognitive architecture model of dance that is based on the idea of mental representation of movements in long-term memory. Schack illustrates how this model can be applied to the study of movement expertise in sports and dance and raises implications for psychological training methods. David Rosenbaum (*Shall we dance? Action researchers and dancers can move together*; Chapter 2) introduces the concept of goal postures and explains their vital role in motor planning. Rosenbaum shows how continuous movements, from everyday grasping actions to dance, are anticipated and stored in memory by the mental representation of goal postures. Holk Cruse and Malte Schilling (*Getting cognitive*; Chapter 3) demonstrate how a biomimetic computer simulation of walking behaviour can be augmented to develop internal world models and, progressively, become "cognitive". Cruse and Schilling take a computational approach based on artificial neural networks to explain phenomena ranging from motor control to subjective experience and even illusions. At the end of the first part, Bettina Bläsing

(*The dancer's memory: Expertise and cognitive structures in dance*; Chapter 4) shows how movement can be studied on different levels, including the cognitive one. Bläsing illustrates how information is stored in the dancer's long-term memory and presents a study in which dancers of different expertise levels were compared based on the quality of their mental representations of classical dance movements.

In Part II (*The dance perspective*), professionals from the dance world report on their practical work and share their experiences of how dance relates to cognition in dance education, pedagogy and choreography. Martin Puttke (*"Learning to dance means learning to think!"*; Chapter 5), former Director of the State Ballet School Berlin and Director of the aalto ballett theater Essen, explains why cognitive skills make good dancers. By giving examples from his rich experience of developing world-class dancers, Puttke shows how ballet teachers can improve their dancers' physical and artistic qualities by substantiating the training process with cognitive methods. Choreographer Gregor Zöllig (*Searching for that "other land of dance": The phases in developing a choreography*; Chapter 6) describes the process of finding novel movements while creating a choreography. Zöllig, who portrays himself as a traveller in "that other land of dance", prefers a working style that integrates ideas and improvisations of his company into the creative process. Galeet BenZion (*Overcoming the dyslexia barrier: The role of kinesthetic stimuli in the teaching of spelling*; Chapter 7), dancer, choreographer and primary school director, introduces her pedagogical concept called the "kinematics teaching method". BenZion has developed this method to help children with learning difficulties, especially related to dyslexia, to acquire their own way of learning by creating meaningful movements.

In Part III (*Neurocognitive studies of dance*), scientists present recent studies that bridge the gap between neurocognitive research and dance, showing how dancers as experimental subjects can help to enlighten our understanding of the ways in which the human brains process different aspects of movement. Beatriz Calvo-Merino (*Neural mechanisms for seeing dance*; Chapter 8) demonstrates how the discovery of mirror neurons in the brain has influenced the way cognitive neuroscientists think about movement, and presents her studies on action observation and dance expertise. Subsequently, Calvo-Merino illustrates how the human brain might generate the aesthetic evaluation of beauty we experience while watching dance. Emily S. Cross (*Building a dance in the human brain: Insights from expert and novice dancers*; Chapter 9) introduces the concept of an *action observation network* in the human brain and explains the role of this network in learning complex movement sequences in dance. Cross and colleagues have investigated how activity in the dancers' brains changes over the course of learning a new movement sequence or choreography, and how this differs in dance experts and novices. Finally, Corinne Jola (*Research and choreography: Merging dance and cognitive neuroscience*; Chapter 10) presents the idea of "experimental choreography" and shows how this idea can be put into practice. Jola gives examples from her own works in science and choreography. She has been investigating cognitive abilities of dancers to mentally rotate images of human bodies and to "measure" their own body posture based only on proprioceptive information.

We would like to recommend this book to students and professionals from the fields of psychology, neuropsychology, cognitive psychology, cognitive robotics sport psychology, sport science, movement science, motor control, motor development, kinesiology, dance, choreography, dance education, dance therapy; to teachers who use or want to use (dance) movement as a means of teaching, or who want to teach dance to students of any age. Finally, we hope that our enthusiasm will be shared by many of our readers, and we are looking forward to learning about their ideas and projects in this young field, the neurocognition of dance, in the near future.

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Part I

The science perspective

1 Building blocks and architecture of dance

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Introduction

Dance is a *complex* and *wonderful* phenomenon. In science, when we study dance, we have to deal with its complexity, trying to reduce it to controllable elements and variables. Often we can address only a small part of the complex action and interaction, and it is therefore difficult to see the forest behind the individual trees. As scientists, however, we do not have a choice, we use theoretical models and methods to learn about elements and the construction of dance movements and the relationship between cognitive, motor and emotional skills in dance performance. Furthermore, we can create simulation models to replicate dance moves on a computer screen or on robots. These steps are similar to the first steps in learning a dance: there is much insecurity, and less stability and grace. Hence, dance seems to be an appropriate example to see the difference between first order reality, dance itself, and second order reality, the scientific theory of dance.

The *wonderful* side of dance is always part of first order reality. It doesn't matter whether we are dancing ourselves or observing a dancer. While dancing, the actor does not normally address elements or details, but rather experiences the "fullness of being" in the here and the now – and therefore achieves a higher level of understanding and interpretation.

Though easy to describe artistically in song or poem, the process of dancing can be very difficult to describe in scientific terms. The fusion of dance with environment and circumstance occurs if one does not plan the movements or think about limbs and their movement kinematics. This can happen if the dancers trust their coordination and capacity to move freely, with flexibility in space and time. The wish to experience this state again and again could be one reason and motivation for dancing in general.

In contrast, when learning to dance or learning a specific movement technique in dance, one pays much more attention to single movement elements and to the dynamics and the kinematics of the movements. The same holds true when one teaches dance movements. This is a task that requires much technical and aesthetic preparation, much work on movement details, as well as on mental and emotional aspects (see Chapters 4, 5 and 7 by Bläsing, Puttke and BenZion, this volume). Sometimes coaches or teachers and dancers simply don't understand each other. This might occur in many ways: They might be addressing different details of the movement, or they might be using different words to describe the same details. Dance teachers and dancers often differ in age and expertise level (see Chapter 5 by Puttke, this volume). Finally, teachers and dancers often have different learning backgrounds or preferences. Therefore it is very important for a good teacher to get a closer insight into the development of the cognitive and biomechanical systems of the dancer. In the light of this requirement, science comes into play and may help practitioners to increase their understanding of the building blocks and the cognitive architecture of dance.

Experts from the field of dance often speak about the function of senses, experience, and movement memory in a dancer's learning of movements. In many interesting discussions with Martin Puttke, Bettina Bläsing and others we have learnt that, in our surprisingly concordant understanding, skill learning in dance is based on different building blocks, such as perceptual information, mental representations of various movement elements in memory (the movement memory bank, see Chapter 5 by Puttke, this volume), and muscle and reflex control in the motor system. We agreed that researchers often make assumptions about the principles governing the combination and cooperation of building blocks of movement in dance. Such building blocks and principles may also have informed the systems developed by Rudolf Laban, Agrippina Vaganova and others (see Box 5.1 in Chapter 5 by Puttke, this volume). Currently, after some new and important steps in movement science (see Schack & Tenenbaum, 2004a, 2004b for an overview), and many years in dance education with only little reflection of new perspectives and methods from cognitive motion science, it is time for scientists, dancers, and dance pedagogues to reflect together on what happens in dance.

Mental representation in dance

Mental representations are important components of dance and human actions in general (Bläsing, Tenenbaum & Schack, 2009; Schack, 2003, 2004a, 2004b; Schack & Mechsner, 2006; see also Chapters 2, 4 and 5 by Rosenbaum, Bläsing and Puttke, this volume). In different areas of dance (e.g., classical ballet, Latin American dance, ballroom dance), mental representation makes it possible to select and combine effective sources of information. Regardless of whether a ballet dancer has to perform a *pirouette en dehors*, a Latin dancer has to select the appropriate *salsa* movement for his partner, or a round dancer has to decide with which member of the group to perform the next figure in a *paso doble* or *waltz*, dancers have to use their mental representation as a foundation to identify possible and functionally relevant sensory inputs. Frequently, this identification has to be made under extreme time pressure. Hence, mental representation in dance has to be available quickly and provide clear criteria for selecting relevant pieces of information. At the same time, mental representation forms the functional basis for a meaningful and, thereby, task-related reduction in the large number of potential moves available to us, our dance partners and the whole performance system. Mental representation in dance does not just facilitate selection of information, but more generally permits a target-related and purposeful adaptation of behavioural potentials to environmental conditions. In other words, mental representation helps to *shape interaction patterns* in dance in purposeful ways. This also includes storing the perceptual-cognitive outcomes of learning processes as items (representations of dance movements) in long-term memory (LTM).

The representational nature and functional role of the LTM structures involved in human movement control remain under much debate in movement science and cognitive psychology. One fundamental issue is the representational medium: Is there a special motor memory completely distinct from perceptual-cognitive structures and processes, or do movements, objects and external events have a common representational medium (Hommel, Müsseler, Aschersleben, & Prinz, 2001)? One prominent theoretical position favours the first alternative, while assuming that motor performance basically means the creation and use of muscle-related motor programmes. Characteristic invariants of such motor programmes may be stored in LTM. To provide an example, Schmidt's (Schmidt & Lee, 1998) *theory of generalized motor programmes* suggests that relative durations as well as relative forces in patterns of muscular activation define invariants of motor programmes that are stored in LTM. This theory also posits that the absolute duration and absolute force also need to be planned for motor performance, but that this is done in a situation-specific way.

An alternative view suggests that movements are organized and stored in memory as perceptible events through a mental representation of anticipated characteristic (e.g., sensory) effects, with the corresponding motor activity automatically and flexibly tuned to serve these effects. A number of scientists (e.g., Mechsner, Kerzel, Knoblich, & Prinz, 2001; Schack & Mechsner, 2006; Rosenbaum, Chapter 2 this volume; see Schack & Tenenbaum, 2004a, 2004b for an overview) hypothesize that voluntary movements follow perceptual-cognitive (mental) representations. In a similar vein, Ivry and colleagues (Ivry, Diedrichsen, Spencer, Hazeltine, & Semjen, 2004) as well as Weigelt and colleagues (Weigelt, Kunde, & Prinz, 2006) hypothesize that central costs and interference in bimanual movements depend solely on how these movements are represented on a cognitive level. Assuming that these hypotheses of perceptual-cognitive control are correct, it seems plausible to generalize them to more complex tasks such as those performed by dancers (Bläsing et al., 2009; Geburzi, Engel, & Schack, 2004; see also Chapter 4 by Bläsing, this volume). In his chapter in this book (Chapter 2), David Rosenbaum assumes that the representation of intended body positions plays an important role in performing dance movements. Following such a perspective, we could imagine that cognitively represented body postures as perceivable key elements are guiding dance movements during the whole performance. Emily S. Cross describes in Chapter 9 of this book how the human brain works when a spectator observes biological movements. The results of her studies could be used as arguments in favour of perceptual-cognitive effect-representations of complex dance movements in the brain. Additionally, Chapter 8 by Beatriz Calvo-Merino supports the idea that spectators perform an internal simulation of the complex dance movements they observe, which is represented in the brain. Dancers seem to code external motor events through their own motor repertoire, using cognitive representations of perceptual effects experienced in the context of body postures while dancing. The aspect of motor simulation can also be of high relevance for choreographers when creating dance, as is illustrated in Chapters 6 and 10 by Gregor Zöllig and Corinne Jola. Taken together, these approaches and studies indicate that movement control in dance is based on the representation of anticipated effects, leading to the establishment of a perceptual-cognitive control system. In their chapter in this book (Chapter 3), Holk Cruse and Malte Schilling present a perspective on how such perceptual-cognitive movement control can be simulated using a neural network model.

To gain a better understanding of the functionality of representation and cognitive categorization in motor control, this chapter starts with a model addressing the cognitive architecture of dance. It then considers relevant issues in research methodology and presents methods that can be used to assess action-relevant knowledge structures experimentally. Further, empirical studies based on these methods are used to show relations between cognitive representation and performance in different human movements. In addition to the cognitive background of dance, emotions such as happiness, stage fright, stress and anxiety are important as well. Therefore, this chapter integrates the concept of emotions in the dance architecture model. Finally, in an effort to open up a perspective for the development and stabilization of performance in dance, this chapter addresses the topic of mental training.

Cognitive building blocks and the architecture of dance

The fact that something like the "model of the needed future" (Bernstein, 1967), and thereby anticipated movement effects, plays a central role in the implementation and control of action is easily understood by dancers. While performing movements, dancers address different effects in their own body. Dancers "speak" with their partners and the audience by means of movement expressions. Therefore, it is of central meaning for them to anticipate keypoints (i.e., body postures) of dance movements, interaction patterns, or whole choreographies.

The function of a "model of the needed future" can be seen clearly in a set of studies addressing the *end-state comfort effect* (e.g., Rosenbaum, Chapter 2, this volume; Rosenbaum, Cohen, Jax, Van Der Wel, & Weiss, 2007; Rosenbaum, Cohen, Meulenbroek, & Vaughan, 2006; Rosenbaum &

Jorgensen, 1992; Weigelt et al., 2006; Weigelt & Schack, 2009). This research has shown that individuals are prepared to adopt uncomfortable positions with their hands when initiating and executing object manipulations, as long as this leads to a comfortable position for the final (end) state of the movement. For example, to pick up a pencil that is pointing upwards in a cup, one initially uses an awkward underhand grip to ultimately hold the pencil in a comfortable writing posture. Such observations show clearly that movements are planned, controlled and performed with reference to the anticipated final position of the movement. Hence, they indicate the existence of a *mental model* (of the needed future) to which all control processes can be related.

As we know from actions and movements in everyday life or movement in sports or dance, parts of our actions are sometimes unanticipated. We observe processes of automatization or a direct activation of movements in the context of special stimuli (e.g., grasping pieces of chocolate when we see a chocolate bar). In the case of dance, especially when dancers perform systematically wrong actions (errors) in special parts of a movement or choreography, dancers and teachers learn about the difference between anticipated and real effects. Often dancers and teachers spend much time to de-automatize unadjusted movement elements. Therefore, it is useful to think about different levels of movement organization in dance and complex movements in more general terms. There have been several iterations of the idea that movement control is constructed hierarchically (e.g., Bernstein, 1947). One set of studies focused on a hierarchy of levels of representation (see, e.g., Keele, 1986; Perrig & Hofer, 1989; Rosenbaum, 1987; Saltzman, 1979). Other studies, in contrast, have focused more strongly on the aspect of a hierarchical execution regulation (e.g., Greene, 1988; Hacker, 1998; Keele, Cohen, & Ivry, 1990; Rosenbaum, 1987). In contrast, the model proposed here views the functional construction of actions (Schack, 2004a; Schack & Bar-Eli, 2007; Schack & Hackfort, 2007) on the basis of a reciprocal assignment of performance-oriented regulation levels and representational levels (see Table 1.1). These levels differ according to their central tasks on the

Table 1.1 Levels of action organization

Code	*Level*	*Main function*	*Subfunction*	*Means*
IV	Mental control	Regulation	Volitional initiation Control strategies	Symbols Strategies
III	Mental representation	Representation	Effect-oriented adjustment	Basic action concepts
II	Sensorimotor representation	Representation	Spatial-temporal adjustment	Perceptual effect representations
I	Sensorimotor control	Regulation	Automatization	Functional systems Basic reflexes

Source: Schack (2004a).

regulation and representation levels; therefore, each level is assumed to be functionally autonomous.

The *level of sensorimotor control* (I) is linked directly to the environment. In contrast to the *level of mental control* (IV), which, as explained below, is induced intentionally, the level of sensorimotor control is induced perceptually. As such, it is built on functional units composed of perceptual effect representations, afferent feedback, and effectors. The essential invariant (set value) of such functional units is the representation of the movement effect within the framework of the action. The system is broadly autonomous; therefore, automatisms emerge when this level possesses sufficient correction mechanisms to ensure the stable attainment of the intended effect.

The need for a certain *level of sensorimotor representation* (II) is apparent in this context. It can be assumed that this is where the modality-specific information representing the effect of the particular movement, among other information, is stored. Subsequently, relevant modalities change as a function of the level of expertise in the learning process and as a function of the concrete task. For instance, when we practise a salsa movement at the beginning of the learning process, we need much more visual information about our body postures and movement timing. Later in the learning process, proprioceptive information about our movement, postures and impulses gains increased meaning.

The *level of mental representation* (III) predominantly forms a cognitive workbench for level IV, the mental control level, and has already been linked to voluntary movement regulation and the coding or anticipated outcome of the movement. Level III is organized conceptually, and is responsible for transforming anticipated action outcomes into movement programmes that sufficiently bring about the desired outcomes. Because an action is "no chain of details, but a structure subdivided into details" (Bernstein, 1988, p. 27, translated), action organization has to possess a working model of this structure. Therefore, mental representations of movement structures are located within level III.

Basic action concepts (BACs) have been identified as major representation units for such mental representation in motor control (Schack, 2004a, 2004b; Schack & Mechsner, 2006). BACs are created through the cognitive chunking of body postures and movement events concerning common functions in realizing action goals. They do not refer to behaviour-related invariance properties of objects as is the case with object concepts; rather, they refer to perception-linked invariance properties of movements. Their characteristic set of features results from the perceptive and functional properties of action effects (i.e., they tie together functional and sensory features). These functional features are derived from action goals, which connect BACs to level IV. Furthermore, BACs integrate sensory features of submovements of an action, for example through chunking (see Verwey, Abrahamse, & Jiménez, 2009). As a result, they also refer to the perceptual effects of movements. This connects BACs with level II. Finally, the connection between BACs and sensory effect representations permits the intentional manipulation of the cognitive framing conditions of sensorimotor coordination.

Taken together, BACs can be viewed as the mental counterparts of functionally relevant elementary components or transitional states of complex movements. They are characterized by recognizable perceptual features, can be described verbally as well as pictorially, and are often labelled with a linguistic marker. For example, "turning the head" or "bending the knees" could be construed as basic action concepts in the case of a complex floor exercise or a pirouette in ballet (see Chapter 4 by Bläsing, this volume). As mentioned above, each individual BAC is characterized by a set of closely interconnected sensory and functional features. For example, a BAC in tennis like "*whole body stretch motion*" is functionally related to providing energy to the ball, transforming tension into the swing, stretching but remaining stable, and so on. Afferent sensory features of the corresponding submovement allow for monitoring the initial conditions (e.g., bent knees, tilted shoulder axis, body weight on the left foot). Furthermore, re-afferent sensory features allow for monitoring whether the functional demands of the submovements have been addressed successfully: muscles stretched and under tension, proprioceptive feedback, and, perhaps, visual perception of the swinging arm and ball in view.

BACs as representations of body postures that are characterized by a set of sensory and functional features are of central meaning in dance. To perform particular dance movements with high accuracy, dancers need sophisticated cognitive representations of goal postures, their functional meaning and the related perceptual events in their own body (and, to some extent, in the audience). Ballet dancers, for instance, have a higher accuracy in position matching of the upper limb than non-dancers (Ramsey & Riddoch, 2001), implying that the representation of body positions can improve goal-directed motor performance. BACs also include information from different sensory inputs. To investigate how the codification of sensory inputs is used to build up mental representations, Hugel and colleagues studied the functional meaning of visual input for artistic purposes in ballet (Hugel, Cadopi, Kohler, & Perrin, 1999). The authors compared the performance of 18 professional ballet dancers to 46 non-dancers in posturographic tests on a force plate, comparing open and closed eyes conditions. Dancers performed better than the control group only in open eyes conditions, which indicates that not only proprioceptive but also visual information plays a functional role in ballet. This perspective is supported by a study of dynamic patterns in postural sway in which ballet dancers were compared to track athletes (Schmit, Regis, & Riley, 2005). The authors found no differences between the groups regarding their variability profile of postural sway in an open eyes condition. In a closed eyes condition, however, the variability increased for both groups in different ways. In dancers, the postural sway was less stable and less complex (showing lower entropy) than in track athletes. The finding that dancers exhibit and represent different dynamic patterns in postural sway could be a result of their specialized training in balance and body control. As we learnt in studies of mental representation in ballet (Bläsing et al., 2009; Chapter 4 by Bläsing, this volume), BACs are key elements for motor control and performance in dance, including representations of body postures and sensory inputs that are also linked to patterns in postural sway. The same applies to Latin American dancers (Geburzi et al., 2004).

These findings lead us to the question of how we can conceive the mental structures underlying complex movements. Is it possible to confirm mutual overlaps between representation structures and movement structures in humans? Is there a similar categorization in representation and movement? If so, how can we use this information for different kinds of mental training? To answer these and other pertinent questions, the chapter will now review extant lines of empirical research, beginning with representations in LTM.

Structures in action and memory

Simplification in the domain of cognitive operations and movement structures in dance is accompanied by order formation. Such order formation in action knowledge reduces the cognitive effort required to activate relevant information. In general, cognitive structures have been shown to improve when more problem-solving-related classifications (concepts) are formed. In the present perspective, in dance, we have to solve *movement tasks* purposefully and linearly within the framework of a voluntary organization of dance movements. Therefore, it is of interest to learn about the task-related order formation of action knowledge.

There are some interesting and elegantly designed studies concerning the functioning and structure of memory in dancers. For instance, Smyth and Pendelton (1994) studied the ability of dance experts and novices to remember both ballet-like movements and nonsensical movements. The authors found that dance experts remembered both types of movement for a longer duration than novices, using cognitive markers to bind the movements to other contents of their LTM. In a study by Starkes, Deakin, Lindley, and Crisp (1987), participants had to recall movement sequences that were either presented verbally or performed by the participants themselves. Results showed that dance experts performed better than novices at recalling choreographically structured sequences, but not at recalling unstructured sequences. Combined, the results of these studies emphasize the importance of mental representations for the learning of dance movements and point towards the quality of these representations as providing a vital marker of dance expertise.

Recent neuroscientific studies show that motor expertise and the expertise-dependent activation of the neurocognitive system is an important factor for the valid prediction of observed movements (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, Hamilton, & Grafton, 2006). These studies provide strong evidence for the notion that involvement of the neurocognitive system while observing complex movements depends on the motor experience of performing the observed movements, and not merely on the observer's immediate visual experience. Thus, mental simulation involving respective cortical areas is only possible for movements that exist within the observer's own movement repertoire (see also Chapters 8 and 9 by Calvo-Merino and Cross, this volume).

An important question that remains is: What is the cognitive basis for mental simulation, for a quick and effective perception of action-related cues, and for producing stable movements in dance? To learn about the relationship between memory and action structures in dance, Geburzi and colleagues (2004) used an experimental method called *Structural Dimensional Analysis – Motoric* (SDA-M) to evaluate the cognitive structure of dance representations in LTM. The authors compared the representation structure of different groups of Latin American dancers: world leading dancers (n = 10), dancers from the European top 20 (n = 10), beginners (n = 15) and non-dancers (n = 12). The investigation focused on the rumba forward step, allowing for consistency across groups. Results showed expertise-dependent structure formation of mental representations in LTM: the higher the dancers' level of expertise, the higher was the degree of order formation in their LTM. Furthermore, the results of the experts' group showed an overlap between LTM structures and (biomechanically defined) movement structures. Another study was designed to elicit differences in dancers' mental representations varying in skill level in two basic ballet movements (Bläsing et al., 2009, see also Chapter 4 by Bläsing, this volume). Participants in this study showed movement-specific differences in the mental representations in LTM related to their skill level. A similar cognitive structure was noted in advanced amateurs and professionals for the *pirouette en dehors*, which referred clearly to the movement structure, and less functional representations in beginners. For the *pas assemblé*, experts' representation structure was different from the ones implemented by amateurs and novices, pointing to differences in movement execution patterns. These data point to a unique mental representation as a function of skill level and movement nature.

To introduce our method for measuring action representation (SDA-M) in this chapter, we have chosen the front loop (end over) in windsurfing as an example, because it seems well suited for an investigation of representational structures at different levels of expertise. In the front loop, many degrees of freedom in the musculoskeletal system have to be controlled, and performance quality is influenced considerably by training and expertise. The front loop is a finite, recognizable (and thereby flexible) action pattern, the overall structure of which is well defined by biomechanical demands.

Until 1986, the possibility of performing an "end over" (see Figure 1.1) was only speculative. Nobody knew for certain how the impulse for forward rotation might be generated from an ongoing forward motion. In 1987, Cesare Cantagalli became the first to perform a forward rotation (which was therefore titled "Cesare roll", and later on "cheese roll") in an international

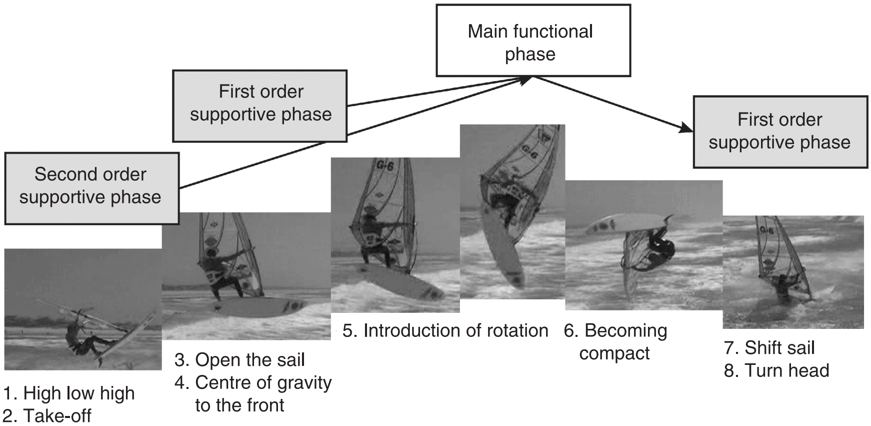


Figure 1.1 Movement phases of the front loop in windsurfing. The task-related basic action concepts (BACs) are allocated to the respective phases. In the take-off phase, the front loop can hardly be distinguished from a regular jump. The surfer waits until the angular point of the slope angle, and then abruptly pushes the sail's pressure point forward and down. Robby Naish entitled this time lag before the introduction of the front loop the "moment of shock for the spectator".

competition at Maui, Hawaii. This led to a boom of experimentation with highly complex movement actions among other professional windsurfers. Mark Angulo turned this sideways rotation into the spectacular front loop (end over) with the characteristic rotation over the mast top (see Figure 1.1). The front loop is executed through rotation around the horizontal axis and rotation around the longitudinal (vertical) axis. This movement is a technical challenge for both excellent amateur windsurfers and competitive professionals, as many highly skilled windsurfers are unable to perform jumps involving forward rotations.

In assessing the movement phases of the front loop in windsurfing, BACs were ascertained for its functional phases. This made substantial contributions to the solution of the movement task and connected movement problems. To permit an allocation to the biomechanically (functionally) determined movement phases, these BACs are listed in Figure 1.1. The concepts relevant for the front loop movement were gathered through a multi-stage process. First, a group of expert (n = 8) and novice (n = 7) athletes gave spontaneous descriptions of the front loop movement. Subsequently, they were interviewed individually with reference to the BACs from their point of view. BACs were not only labelled verbally, but also demonstrated as a specific movement pattern. Following an active execution of the movement, the former results were complemented or corrected through video-based self-confrontation. Later, these findings were also controlled by allocation experiments (Schack, 2002). The acquired BACs for the front loop were: (1) high low high; (2) take-off; (3) opening the sail; (4) moving centre of gravity to the front; (5) introduction of rotation; (6) becoming compact; (7) shifting the sail; and (8) turning the head.

Because the usual rating and sorting methods do not permit a psychometric analysis of the representational structure, we developed an experimental method for probing mental representation structures (SDA; Lander & Lange, 1996; Schack & Schack, 2005). It has now been modified for the analysis of action representation (SDA-M; Schack, 2004a). This experimental approach has been documented in several contributions (Bläsing et al., 2009; Hodges, Huys, & Starkes, 2007; Schack, 2004a, 2004b; Schack & Hackfort, 2007; Schack & Mechsner, 2006).

The SDA-M method consists of four steps. In the first step, participants were familiarized with the above-mentioned BACs by looking at pictures with a verbal BAC label as a printed heading. These pictures remained positioned in front of each participant throughout the experiment. In order to determine subjective distances between the BACs, the participants performed the following splitting procedure as the first step in the SDA-M. On a computer screen, one selected BAC was presented constantly as an "anchoring unit" in red writing. The rest of the BACs were presented in yellow writing as a randomly ordered list. The participant judged whether each of the random (yellow) BACs was "functionally related" (associated) to the anchor (red) BAC "while performing the movement" or not. This produced two subsets that were submitted to the same procedure repeatedly until no further splits were applicable. Each BAC was used as an anchoring unit, which resulted in eight decision trees per participant. In the second step of the SDA-M, we submitted the aforementioned BACs to a hierarchical cluster analysis, with distances based on subjective distance judgements of all combinations of pairs of BACs obtained in the previous step. As a result, we obtained the individual partitioning of the BACs. In the third step, the dimensioning of these cluster solutions was performed using a factor analysis applied to a specific cluster-oriented rotation process. This resulted in a factor matrix classified by clusters (for a study in tennis, see Schack & Mechsner, 2006; in social cognition, see Schack & Schack, 2005). Finally, in the fourth step of the SDA-M, cluster solutions were tested for invariance both within and between groups (for details, see Hodges et al., 2007).

A total of 40 experts and novices participated in an additional study to develop new forms of technical preparation. The 20 experts (all male; mean age 28.8 years; engaged in windsurfing for 15.8 years on average; performing front loops for 9.4 years on average) consisted of American, French and German athletes who were counted among the world elite in windsurfing at that time. Several among them were pioneers of windsurfing, having been involved in the movement from its beginning. They all participated in international competitions (World Cup, Grand Prix, etc.) as professional windsurfers. Each of them could perform the front loop reliably and variably in a competitive setting (some even as a double front loop), and reported training, on average, for about 30 weeks annually. Expert status was defined as the ability to perform front loops on a competitive level for at least 7 years.

The 20 novice athletes (18 males, 2 females; mean age 22 years; engaged in windsurfing for 8.2 years on average; performing front loops for 1.6 years on average) were mostly German and American athletes. They reported training for approximately 23 weeks annually, and participated in both national and international competitions. However, they had no rankings worthy of mention, and were unable to perform the front loop under competitive conditions. Overall, their (potential) scope for development was comparable to the expert group. Hence, these were persons with the capability to reach an expert level who had not yet achieved that status. One of the main assumptions of the study was that the novices mastered the technical execution of the front loop far less reliably and regularly than the experts. Experts stated that mastery depends highly on experience in windsurfing and repeated practice under various conditions. The minimum condition for acceptance in the novice group was to have performed the front loop at least twice, according to their own reports. The results of this study are illustrated in Figures 1.2–1.4 (for which α is constantly set at .05, allowing for a d_{crit} value of 3.51).

Figure 1.2 displays the group structure of the windsurfing experts, based on cluster analysis in the form of a dendrogram, and reports the factor matrix arranged according to the three clusters. The structures of mental movement representation in the expert group showed a remarkable affinity to the biomechanical functional structure of the movement. As Figure 1.1 shows, the

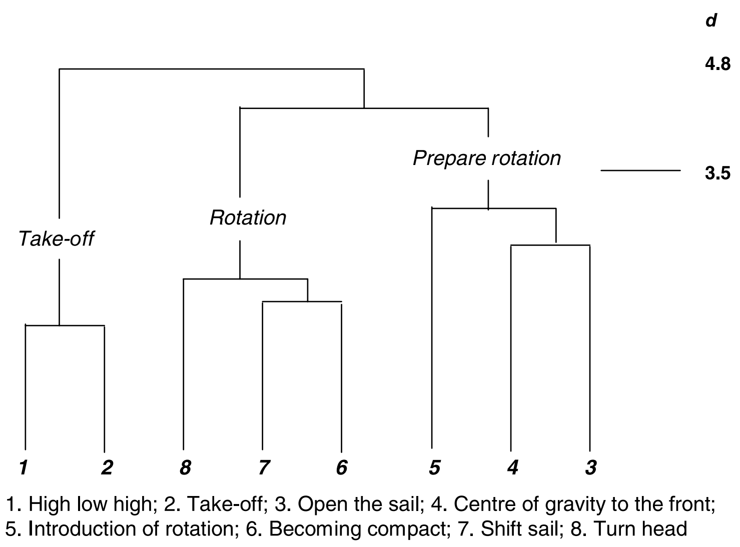


Figure 1.2 Results of the hierarchical cluster analysis of BACs for the front loop in the expert group. The lower the value of an interconnection between the study units (see the Euclidian distance scale on the right), the lower the distance of the concepts ($n = 20$; $\alpha = 5\%$; $d_{crit} = 3.51$).

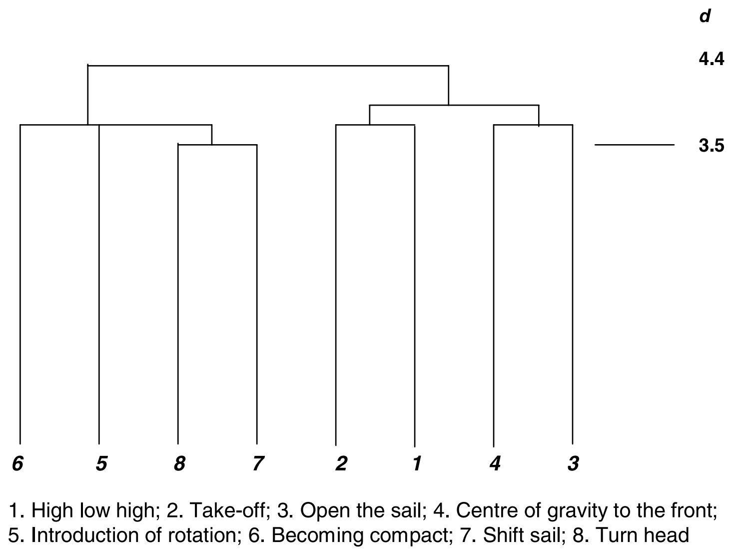


Figure 1.3 Results of the hierarchical cluster analysis of BACs for the front loop in the novice group (n = 20; α = 5%; d_{crit} = 3.51).

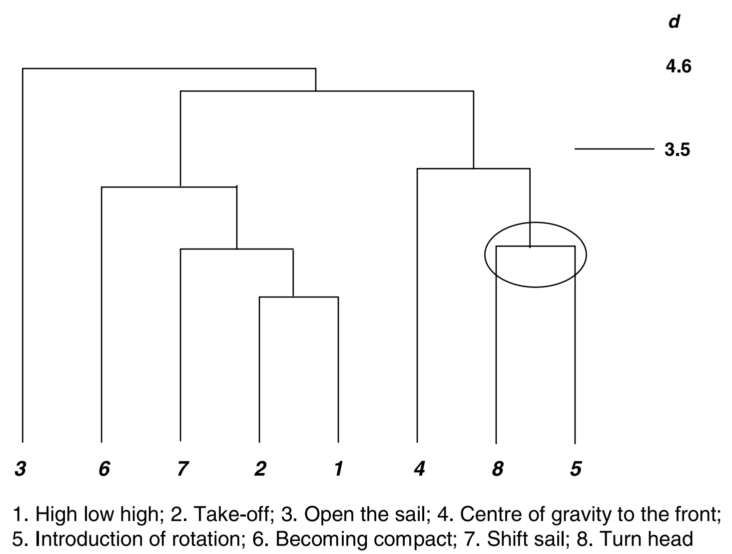


Figure 1.4 An individual novice's solution (subject 4) in the learning stage of rough coordination as an outcome of hierarchical cluster analysis. The circular mark denotes a link between two elements that is obviously based on surface features (α = 5%; d_{crit} = 3.51).

functional structure of the movement could be divided into several phases, with *take-off* being classified as second-order supportive phase, *preparation of rotation* as first-order supportive phase, and *rotation* as the main phase. Experts' superordinate concepts (take-off, preparation of rotation, rotation; see Figure 1.2) were acquired on the basis of clusters and are spatially distinct and organized in a temporal sequence. Therefore, we assume that they serve as a means to solve specific subproblems of the movement (energizing, introduction of impulse, rotation).

Figure 1.3 illustrates the cluster solution for the novice group. The cluster solution reveals a weak structural link between elements. The BACs are located slightly above the critical distance ($d_{crit} = 3.51$). Therefore, no structure could be confirmed for the whole group, the technique-related representational structures seem at this point to be too weak. The claims regarding movement representations in individual cases, though, are particularly interesting for technical preparation.

The dendrogram of the novices revealed a significant difference in their clusters compared with those of the expert group. Whereas the expert cluster solution followed a functionally based phase structure of the movement, no comparable structure could be found in the novice cluster. Here, elements were arranged differently, and neither a phase-related clustering nor a temporal-sequential structure could be identified. Furthermore, inexpedient mental structures were apparent. Subject 4 (see Figure 1.4) combined elements from different movement phases. This resulted in a cluster consisting of elements 5 (rotation) and 8 (head turn). Although both elements of the cluster represent rotation motions, they have functionally nothing in common. Whereas element 5 plays an important part in the introduction of the rotation, element 8 completes the rotation. Superficial features, not functional features, were consulted when classifying the elements; therefore, the unification of these elements on the representational level is often linked to typical movement errors at this level of motor learning, because of poor coordination. In this context, novices often forget the head turn needed to complete the movement, which can lead to dangerous falls.

In the current study, we were able to confirm the relation between cognitive representation and performance for a special movement technique in windsurfing. The cognitive structure of persons with high ability was more differentiated, and more strongly function-oriented, than that of beginners. Subsequently, it can be argued that experts are better able to apply their knowledge in practice when aiming for optimal execution of a given movement. Furthermore, we have put forward statements regarding cognitive structures that are directly relevant for training processes. These statements can help to decide which cognitive contexts athletes can understand and which contexts they might work best in. This is particularly relevant for movements that have to be carried out under extreme time pressure.

Are these LTM structures we have measured the ones that also functionally underlie movement performance? At the present time, we consider this to be the case, because it is plausible that LTM structures exist within the context of a perceptual-cognitive, or anticipatory, control scheme, as hypothesized above. Indeed, we can see no other way of addressing the functional demands related to BACs other than by controlling the corresponding submovements directly through their anticipated perceptual effects. As we have emphasized, characteristic perceptual features of BACs relate meaningfully to corresponding functional features. For example, sensory feedback tells athletes whether or not they have performed the movement properly and effectively. Taken together, it is plausible that functionally successful movements require the use of an anticipatory control that draws on BAC networks. We conclude, then, that the controlling system may well use the revealed cognitive BAC networks in LTM to construct situation-specific reference structures for anticipatory control.

Consequences for technical preparation and mental training can be derived from such analyses of the representational and biomechanical structures of a movement. It becomes possible, then, to ascertain the phase of the movement in which representational problems are located. Subsequently, technical preparation and mental training can inform this motion sequence. In this light, a specific teaching method has been developed for this purpose. We call this method *mental training based on mental representation* (MTMR) (Schack, 2004a; Schack & Bar-Eli, 2007; Schack & Hackfort, 2007). We will come back to this topic in a later section.

Horizontal and vertical cooperation within the architecture of action

Results from different lines of research addressing mental representation showed that the structure formation of representations in LTM as well as chunk formations in working memory are built up on BACs and relate systematically to movement structures (Schack, 2004a). Experiments were designed to assess both the structure of mental representations in LTM (determined via SDA-M) and chunking in working memory (determined via *cognition and movement chronometry*, CMC; see Schack, 2004a). If the interaction assumption is true, identifying functional modules of the movement architecture with both groups of experiments should make it feasible to match indications of structure in LTM with those in working memory. Results, in fact, have confirmed this, demonstrating that cognitive systems interact to produce complex movements. Our experiments have shown that both the order formation in LTM (Schack, 2004a, 2004b; Schack & Bar-Eli, 2007; Schack & Hackfort, 2007; Schack & Mechsner, 2006) and the chunking in working memory (Schack, 2004a) are based on the topological (spatiotemporal) structure of the movement. This provides experimental evidence that structures in movement and memory mutually overlap.

To gain a fuller understanding of the cognitive architecture of complex movements, it is important to know whether LTM and working memory cooperate horizontally on the level of mental representations. Furthermore, it is also crucial to know whether there is vertical cooperation between the level of mental representations and the level of sensorimotor control. An inherent question then becomes whether biomechanically relevant features can be found in the structure of mental representations. Some of our studies have been designed in an attempt to systematically answer this question by searching for pathways between biomechanical aspects and mental movement representation (Heinen & Schack, 2003; Schack, 2003). This has required us to develop new methodological approaches to measure kinematic parameters as well as the structure of mental representations.

Experimental studies (e.g., Schack, 2003) show that representational frameworks are organized in a hierarchical tree-like structure and reveal a good match with the biomechanical demands of the task. After measuring kinematic parameters, Schack and colleagues investigated the relationship between the structure of motor representation and the kinematic parameters of different movements. These studies (Heinen & Schack, 2003; Schack, 2003) have revealed significant correlations between kinematic parameters (e.g., time structure, angles according to the take-off phase, tilt angle, angular velocities) of movements and the corresponding parts of mental representations. Hence, the results suggest that there is a level in the organization of movement from which representations are translated directly into movement. According to this perspective, the representation structure can access all the topological properties that support the movement. It can also be inferred, then, that no special translation mechanism is required between perception, representation, muscle control, and movement performance. Altogether, our experimental results support the hypothesis that voluntary movements are directly stored in memory through representations of their anticipated perceptual effects.

Emotions in the architecture of dance

Performers in many areas such as dance and sport exhibit a high level of performance in practice, yet sometimes struggle under the stressful conditions often presented on stage or in game situations (see Beilock & Gray, 2007 for extensive review). Even though motor skills and mental representations of these skills are inherited and learnt, a performer's use of them might be altered under emotional and temporal pressure. How, though, might the cognitive architecture of dance change under pressure? What are the underlying mechanisms that permit or prevent an efficient course of action? Though sound theories and extensive research have been devoted to exploring this linkage, empirical efforts have yet to take an integrative approach. Therefore, questions such as these cannot be answered with confidence at this time. In that light, this chapter will now offer an initial road map to understand mental and motor operations in relation to emotions in dance performance.

The functioning of motion is based on both cognitive and emotional components of motor control and performance; therefore, our field must pay attention to the functional meaning of emotions, and we should think about ways to integrate the concept of emotions in our cognitive architecture model. From such a point of view, negative emotions such as anxiety should be understood not only as having an undermining effect on performance, but as a process of adaptation to specific situations, or as a motivating factor for particular actions. (The same holds true, in general, for stage fright; see Mornell, 2002.) A performer's anxiety in a particular moment of an action can reinforce the sensitivity for dangerous or critical situations, prompting the adoption of defensive strategies and their engaging in more realistic decision-making. Carver and Scheier's (1988) control process model of anxiety and performance posits that anxiety can have either facilitative or debilitative effects on performance, depending on a subject's expectancy of being able to cope with anxiety and complete the action. Support for this contention in sport comes from the work of Jones and colleagues, where highly skilled swimmers (Jones, Hanton, & Swain, 1994) and cricketers (Jones & Swain, 1995) interpreted both cognitive and somatic anxiety symptoms as more facilitative to their performance. Swimmers who had positive expectancies of goal attainment interpreted anxiety as more facilitative than swimmers who had negative expectations of goal attainment (Jones & Hanton, 1996). Thus, cognitive anxiety can improve motivation and provide appropriate attentional focus (Jones, Swain, & Hardy, 1993).

The relationship between emotion and cognition from an action-oriented perspective is depicted in Figure 1.5. The appraisal of events, action effects, or stimuli in the environment is the first cognitive process in action organization. Subsequently, the result of one's appraisal is not only stored in memory, but becomes of central meaning for eliciting emotions as well. Stimuli and appraisal-dependent emotions are stored in memory as specific elements of cognitive event profiles and are functionally linked with the initiation and maintenance of motivation. One stimulus, therefore, may produce not only one, but several types of motivation.

At this time, the level of mental control also comes into play. Processing at this level begins with a decision about a relevant course of action. The result of this decision-making process is the intention to achieve specific action effects. Based on this intention, an action plan is created and the mental control processing runs to a module that is responsible for action execution. This module is linked to the level of sensorimotor control (see Table 1.1), and includes all motor components necessary for the production of goal-directed action effects. The type and quality of action effects are important information for the action system. However, if action effects are not congruent to the intended outcomes, or are not valid enough for coping with the actual situation, the appraisal system will read an insufficient action, and will evoke negative emotions. In the case of problems in action realization – if the real situation in competition is much more difficult than the expected one – mental control processing must take a different path. If this occurs, the performer must use action strategies such as control of attention, control of emotion, or

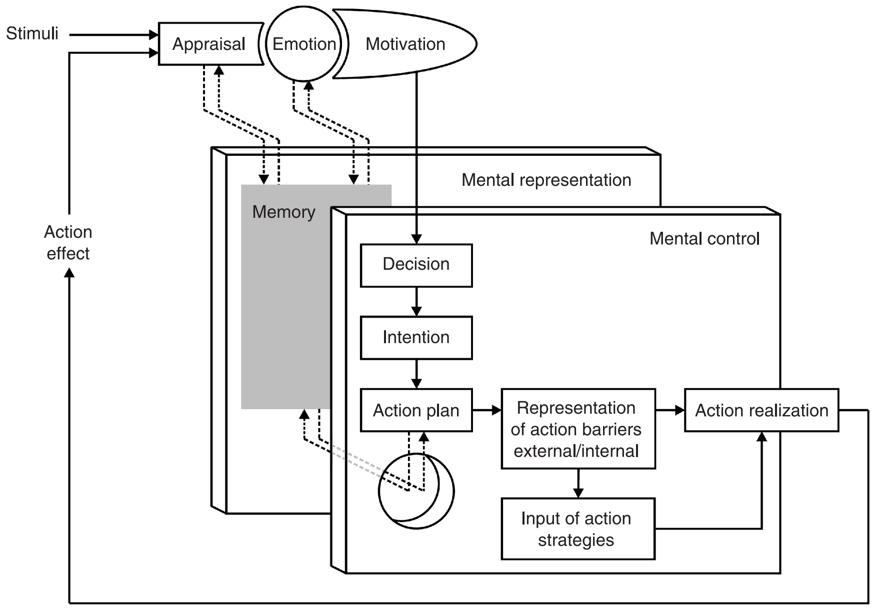


Figure 1.5 Interaction between cognitive and emotional processes and modules in the architecture of dance. Emotions are not only influenced by cognitive appraisal processes and related to memory. Furthermore they have an impact on components of motivation and they are part of the whole perception–action–effect cycle.

motivational control. Such strategies are supported by inner speech, *self-talk*, and are used to stabilize action realization. Thus, if performers lack such strategies, they have no tools to control actions appropriately. Furthermore, if performers lack mental control, they will not realize their intentions and will lack intended action effects. This kind of information is negatively valued by the appraisal system, and influences the development of emotions dramatically. Thus, an important link between emotion and information storage is caused by the representation of emotionally induced action effects in LTM. From this point of view, emotions are part of information storage in general.

Interestingly, the model depicted in Figure 1.5 shows a functional relationship between the level of mental control and emotions. From this point of view, the development of emotions is functionally related to observed action effects. Of additional importance to the formation of emotions is the difference between intended and actual effects, and an individual's appraisal of this difference. For this reason, the model is in accordance with specific emotion theories. For example, Mandler (1979, 1985) assumes that the abortion of a previously planned action can be seen as a central reason for anxiety development. According to Mandler's approach, task-relevant stimuli are perceived in terms of the increased interruption of action. These stimuli demand their own attentional resources, and therefore disturb action performance. Therefore, paradoxically, anxiety might not only be the reason for performance interruption, but also its consequence. The models presented here (see Table 1.1 and Figure 1.5) rest on the assumption that the interruption of activated performance plans and the increasing inability to subordinate action performance to an action programme are attributed negatively and emotionally. Therefore different psychological training methods, like training of inner speech or stress regulation techniques, are helpful to improve mental control and to reduce stage fright or anxiety.

Links between the architecture of dance and psychological training methods

Regarding the actions performed by dance teachers, our theory represents a framework that commonly relates to a practical problem. The crucial assumption is that a theory is primarily used in connection with practical problems, and that its value is subsequently derived from evaluating its practical impact. However, practical steps like training or intervention techniques have to be attached to theory. In this respect, nothing would be more practical than a good theory!

When taking an applied perspective in dance, the theoretical concept of the construction of action (see Table 1.1) is fundamental to both the development of suitable diagnosis procedures and the selection of appropriate training methods. It becomes plausible to define relevant systems of action more precisely. In applied work, it is exceptionally important to understand that such different systems play a part in a dancer's performance. A frequently observed practical problem is that dancers are able to perform a certain movement optimally in practice, but fail to do so on stage or in competitive settings. When movement structure is accessible in less stressful circumstances, yet appears to be optimally represented in the athlete's memory, the problem is likely to be rooted in deficits of mental control. Schack and colleagues have developed specific methods for a reliable diagnosis of how a movement is represented, which enables both researchers and practitioners to control the goal-directedness of psychological training. Problems that may be located, for instance, in the areas of emotion regulation or motivation result from deficits at the level of mental control. Psychological training procedures that intervene at this level, particularly those targeting attention control, optimization of self-talk, and stress and anxiety control (see Figure 1.6) aim to improve basic regulation. In contrast, the structure of a movement – and therefore its optimal technical execution – is largely determined by the level of mental representations. Consequently, training procedures designed to optimize process regulation should be allocated at the level of mental representations.

Theoretical considerations regarding the construction of complex and integrated actions such as dance are helpful when trying to identify suitable

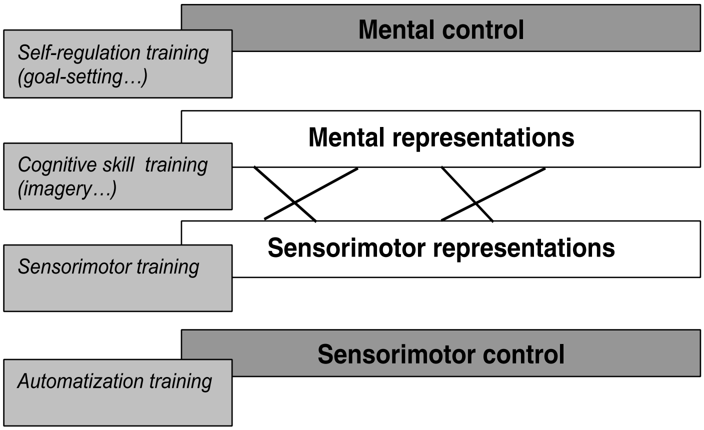


Figure 1.6 Levels of action regulation and related psychological training methods.

psychological training methods for applied work. As stated previously, it is most appropriate to start by using specific diagnostic procedures to investigate the systems involved in the organization of action. In this context, it is important to note that investigators also apply the results of such experimental diagnoses in the consulting process so that athletes receive feedback on their memory structure (Schack & Hackfort, 2007). This diagnosis is important when deciding whether an athlete possesses a good disposition for optimal process regulation. Problems regarding the capacity to perform optimally in competitive or onstage settings may be located in the fields of process regulation and basic regulation. The term *process regulation* refers to the execution-related organization of an action, whereas *basic regulation* describes the generation of emotional and motivational conditions for the action. Basic regulation is primarily produced at the level of mental control. Therefore, Schack and colleagues applied appropriate diagnostic tools to test stress regulation, competition anxiety, self-talk, or different components of volition. Results of this diagnostic test are given to the athlete as a mental profile (Schack & Hackfort, 2007). Such mental profiles can be used to help practitioners make better decisions on appropriate psychological training methods for athletes. If problems are diagnosed at the level of mental control, training methods and strategies to strengthen mental control are preferred. These may be exercises to optimize self-talk, relaxation methods, procedures for optimizing stress regulation, and so forth. If problems concerning movement memory and motor coordination are diagnosed at the level of mental representations, imagery training or technical preparation are more appropriate. The benefit of the synthesis of mental training and memory analysis lies in the consideration of the athlete's individual cognitive dispositions.

New paths in mental training

Studies carried out during the first half of the 20th century indicate that performing mental tasks leads to an improvement in subsequent test performance (Sackett, 1935). More recent studies have been primarily conducted in various fields of sport psychology (Driskell, Copper, & Moran, 1994). In sports, as in dance, the subject of imagery is traditionally movement, and the main aim of movement imagery is to enhance specific motor actions (e.g., Boschker, 2001). Studies examining the effects of mental practice in sports frequently use three or four experimental groups: a control group (CG) that receives no treatment, and at least two experimental groups, one of which practises mentally (M) whereas the other practises physically (P). A third experimental group may practise both mentally and physically (MP), and the most substantial effects are usually found in this group. Feltz and Landers (1983, 1988) reviewed studies in which all four groups were included, but inclusion criteria were broad and mental practice contents were not always comparable. Extant literature shows that the performance of the P group was greater than the performance of both the M and the MP group. Other meta-analyses (e.g., Driskell et al., 1994) did not involve an explicit comparison with MP groups; however, it is apparent that mental practice has positive effects on performance enhancement (effect sizes: .21–.68) (Driskell et al., 1994; Feltz & Landers, 1983; Hinshaw, 1991). Several studies in sports psychology have shown that mental practice alone can be effective in improving the execution of movements in individual athletes and helps the acquisition of new skilled behaviours (e.g., Gould, Damarjian, & Greenleaf, 2002; Morris, Spittle, & Watt, 2005), but these effects may be less significant than those of physical exercise or physical exercise in combination with mental practice (Driskell et al., 1994).

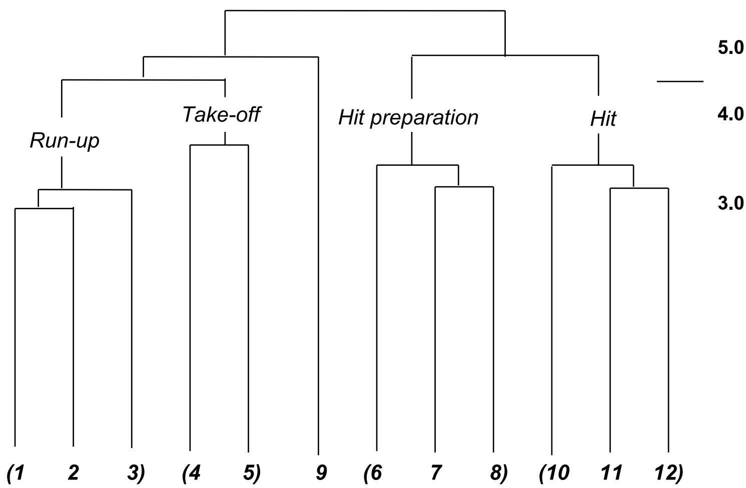
Various theories have been used to explain the effects of mental training (see, e.g., Heuer, 1985; Driskell et al., 1994). The major explanatory models based on current scientific findings can be differentiated according to whether they consider effects to be a result of physically peripheral (neuromuscular) processes or central mechanisms such as symbolic codes or programmes. Recent findings on the cognitive architecture of actions have extended the work on ideomotor action control (Knuf, Aschersleben, & Prinz, 2001; Koch, Keller, & Prinz, 2004). These, in combination with current neurophysiological findings (Jeannerod, 1995, 2004), open up a new explanation for the effects of mental training: the *perceptual-cognitive hypothesis*. This hypothesis posits a representation system in which strong cognitive representation units, or nodes, are linked to perceptual representations (e.g., kinaesthetic, optical, or acoustic effect codes). Because they possess a spatiotemporal structure, these representations can be translated directly into movement. This makes additional motor, spatial-pictorial, or other representations (see, for the symbolic hypothesis, Heuer, 1985) unnecessary for movement control. Another basic assumption of the perceptual-cognitive model is that imaging a movement and performing it are based on the same representations (Jeannerod, 1995; Schack, 2004a). This would explain the impact of mental training by proposing that it internally activates and stabilizes the representation system. Mental simulations of movement may forge, or strengthen, links between the cognitive representation of intermediate states of that movement and the accompanying perceptual effect codes. At the same time, interfering perceptual inputs will be inhibited. Because these representation structures are also conceived of as a hierarchy, mental training also initiates feedback processes between various representation levels (see Jeannerod, 1995; Table 1.1).

This makes the methods developed here (e.g., SDA-M) directly significant for developing new forms of mental training. The main disadvantage of traditional procedures is that they try to optimize performance through repeatedly imagining the movement without taking the individual's mental technique representation into account (i.e., they are representation-blind). However, if the movement's cognitive reference structure has structural gaps or errors, these will tend to be stabilized rather than overcome by repeated practice. The alternative developed here is to measure the mental representation of the movement before mental training and then integrate the results into mental training. This "mental training based on mental representations" (MTMR) has now been applied successfully for several years in professional sports such as golf, volleyball (Schack, 2004b), gymnastics, windsurfing and soccer (Schack & Bar-Eli, 2007; Schack & Hackfort, 2007).

An example of this kind of mental training can be seen in the way professional volleyball players address the ball on a spike. This movement requires at least 12 BACs stored in memory. Because the primary focus is on the memory structure of the movement, in preparation for a mental training programme, Schack and colleagues studied this structure in members of a German women's volleyball youth national team. Findings from quick-spikers with good movement performance (Figure 1.7) were compared to quick-spikers with specific movement problems. In quick-spikers with good movement performance, four different clusters were identified in the mental representation of the attack hit: run-up, take-off, hit preparation, and hit. These substructures are spatially distinct and are ordered in chronological sequence. Figure 1.7 presents the results of a hierarchical cluster analysis for the group of quick-spikers from the German youth national team.

Mental movement representation is structured in exactly the same way as movement organization. Furthermore, the categories determined by the clusters (run-up, take-off, hit preparation, hit) are spatially distinct and ordered in a temporal sequence. Therefore, the specific representation structures are evidently used to solve specific subproblems in the movement.

Player B (see Figure 1.8) had had difficulties in optimally executing the spike for several years. The analysis revealed the cause: BACs 1–3 and 4–5, which are important for the sequence of impulses during run-up and take-off, respectively, point to a less precise memory structure. For this player, run-up and take-off were broken down into two inefficient memory sections (5–2 and 4–3).



1. Taking arms back, 2. Stamp step, 3. Bending knees and trunk, 4. Swinging both arms forward, 5. Extending legs, 6. Body arching, 7. Spiking arm back, 8. High elbow, 9.Glance towards opponent´s block, 10. Spike emphasizing the wrist, 11. Whipping extension of arm, 12. Drawthrough of hitting arm

Figure 1.7 Results of hierarchical cluster analysis for experts (German women's national volleyball team) in the player position quick spiker ($n = 6$, $\alpha = 1\%$, $d_{crit} = 4.55$). The lower the value of a link between two items (see the scale of Euclidean distances on the right), the lower the distance between the BACs in long-term memory. The value for d_{crit} is displayed as a bar splitting the scale of Euclidean distances; it separates the relevant structural links from less relevant ones (above d_{crit}) for a given α probability.

Subsequently, application of an individualized mental training programme tackled the athlete's memory structure problem and developed specific movement imagery for an ideal take-off and a proper spike. Additionally, player B went through a series of run-up and take-off drills designed to train the optimal motion sequence. The focus was on making player B aware of the altered movement so she could develop a new feeling for it. Additionally, the mental training programme aimed to generate this optimal perception of the movement in the complementary mental training. This succeeded in improving player B's spike appreciably; today she is a member of the German Women's A-National Team. The advantage of using mental training and memory analysis in combination lies in the fact that athletes' memory structures are integrated into mental training providing sufficient consideration of their individual dispositions.

Our approach to mental training (MTMR) is currently being applied not only in various professional and amateur sports (Schack & Bar-Eli, 2007, Schack & Hackfort, 2007) but also in rehabilitation for stroke patients by stabilizing and gradually improving their grasping movements (Braun, Beurskens, Borm, Schack, & Wade, 2006; Braun et al., 2007; Braun, Kleynen,

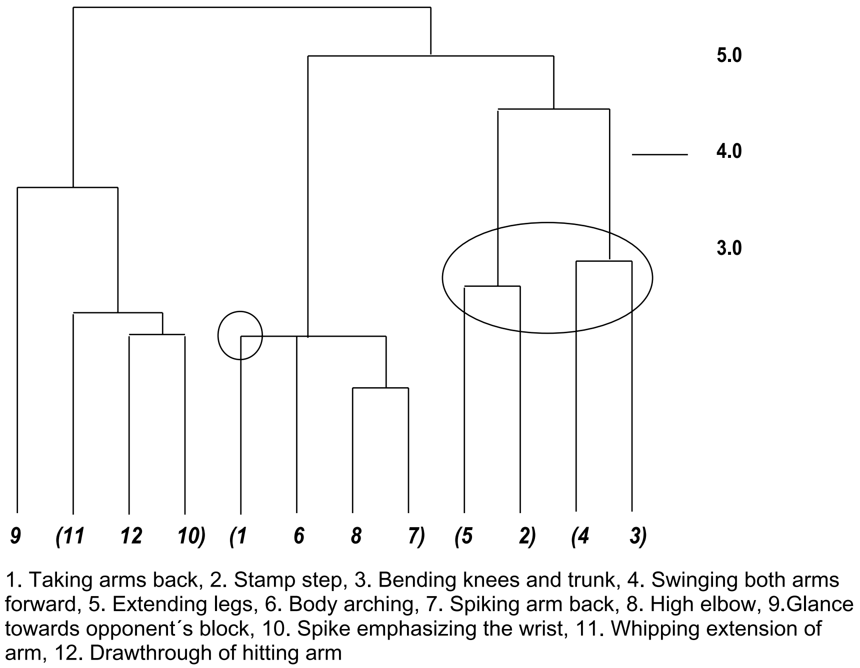


Figure 1.8 Individual representation structure of a German national team player (player B) displaying specific movement problems in regard to the quick spike, shown as a result of cluster analysis (α = 5%; d_{crit} = 3.98). The highlighted positions are explained in the text.

Schols, Schack, Beurskens, & Wade, 2008). In cases of injury, mental training offers a means of training even when active movement execution is severely impaired (for an impressive example, see Chapter 5 by Puttke, this volume). As a result, new opportunities for the use of mental training have come to fruition in medical, orthopaedic and traumatological rehabilitation. In this specialized context, mental training has proved to be of great use when it comes to regaining lost movement patterns after joint operations or joint replacements. Thus, beyond the world of elite sport performance, mental training provides a general means to link together imagery and movement in various areas of life, and especially in dance, where success in movement learning (and rehabilitation) and movement imagery are most crucial for optimizing performance.

Conclusion: when we dance . . . then we take a chance

To support various techniques used by dancers and dance educators, this chapter has presented methods that focus on precisely defined components of actions. It is clearly advantageous for a teacher to know how mental structures are formed, stabilized, and changed during the course of learning a specific dance action. A dance teacher who possesses such knowledge might also be better able to address the individual dancer on his or her current level of learning, and therefore shape instructions specifically for each dancer (see also Chapters 5 and 9 by Puttke and Cross, this volume). The specific methods presented in this chapter make it possible to take essential information regarding the underlying cognitive-perceptual action system into account, while still addressing the individual needs of a dancer in a better way. Furthermore, the theoretical perspective on the construction of dance developed here, and the accompanying methods and technological steps are not just relevant for optimizing the daily work of sport psychologists and dance teachers, but also open up new perspectives for modifying classical dance training, including specific technical preparation and mental training.

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2 Shall we dance?

Action researchers and dancers can move together

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Introduction

Dance, an art form, and action research, a scientific enterprise concerned with the analysis of perceptual-motor behaviours, have had little contact. This is not surprising considering the usual separation of the arts and sciences. However, the gap between these two lines of activity need not persist. Filling the gap holds great promise. Dancers and dance instructors face technical as well as artistic challenges, and action researchers may be able to help dancers address these concerns. Action researchers, on the other side, may benefit from the inclusion of artistic and emotional expression in their portfolio of research interests. By recognizing the challenges of acting gracefully or of acting in ways that convey emotions in musical contexts, action researchers may broaden the scope of their investigations to embrace artistic expression as well as more traditionally studied topics in action research such as efficiency and maximum speed of performance (Fitts, 1954).

My own research, some of which is reviewed here, has been similar to much action research in that it has largely ignored the artistic side of physical expression. In my own case, this is ironic considering that my interest in perceptual-motor control stems largely from my longstanding interest in, and dedication to, violin-playing. The cross-disciplinary approach pioneered here by Bettina Bläsing and colleagues can help investigators like me feel freer to cross the science–art divide.

When I think about dance, two people leap to my mind: Fred Astaire and Ginger Rogers. Regardless of how these two people may be viewed in the "serious" dance world, I have always found them to be geniuses of their medium. Fred Astaire danced as if he were weight-free. Ginger Rogers carried herself just as lightly, plus, as she famously quipped, she did so wearing high heels and while going backwards. The great artistry of these two dancers, like the great artistry of other masters of dance, reflected years of practice. As dancers and other practitioners of physical and artistic expression get better and better at what they do, they learn to plan and control their movements more and more effectively. The nature of this process is what my colleagues and I have been interested in. Our main interest has been in motor planning. The question driving our research is: How do we plan the movements we make?

One way of asking this question is to ask how particular movement patterns emerge when any given physical task is chosen. This problem instantiates the degrees of freedom problem, which arises whenever there are multiple possible solutions to a presented problem (see also Chapter 3 by Cruse & Schilling, this volume). Motor planning tasks epitomize the degrees of freedom problem because, usually, there are many possible ways to achieve a given physical task. Nevertheless, one solution to the task demands invariably emerges. Typically, the solutions are sensible, reflecting the operation of implicit efficiency criteria for movement selection.

Representations

In addressing this topic, my own point of departure as a cognitive psychologist is to focus on the *mental representations* used to guide motor planning. Cognitive psychology is the study of mental function, and at its heart is the concept of mental representations. Mental representations, as their name implies, are states of mind corresponding to experiences. In their simplest forms, mental representations are sensations arising from exposure to sensory stimuli. The mapping from measurable sensory stimuli to measurable sensory experiences or their reports (e.g., magnitude estimations, discriminations, or scaling of similarities or differences) is the subject of psychophysics. More complex mental representations may interconnect, with some representations exciting or inhibiting others. At any given time, a mental representation may also occupy the focus of attention while other mental representations may not. The study of attention is the study of such focusing; it includes the analysis of the dynamics of the transitions between mental representations. Finally, and most importantly for the discussion to follow, mental representations refer to remote objects or events. For example, when light impinges on the retina, we do not "see" the activity of our photoreceptors. Rather, we refer the photoreceptor activity to objects and events in the outer world. Sensations, therefore, are referred; they *represent* what is out there. The same is true of other representations.

Representations of what is out there need not just refer to things in the present. They can also refer to events in the past – what we call *memories* – and to events expected to occur in the future – *predictions* or *plans*. Plans for actions can be thought of as memories for the future. For cognitive psychologists interested in motor planning, the challenge is to understand how such memories are formed, that is, how they are structured and how they are assembled over time (a study that investigates mental representations of dance movements is presented in Chapter 4 by Bläsing, this volume).

A core concept in the study of mental representations, including the mental representations comprising plans for physical actions, is the notion of *hierarchy*. Governing relations exist among mental representations. If one representation, A, excites or inhibits another representation, B, more than the opposite, A can be said to control B. This observation has an important corollary. It is often said that there are *levels* of representations. For example, in the study of speech production, it is generally acknowledged that there are distinct levels of representation for speech (Levelt, 1989). These levels have been inferred from a variety of sources, a prime one being slips of the tongue. Mistakes made in speaking are typically systematic and suggest distinct levels: a semantic (meaning) level, a syntactic (word order) level, a phonological (sound) level, a vocal execution level, and so on. Each level is suggested by characteristic errors that can be attributed to the mixing or missing of elements within the hypothesized tiers. For example, verbs tend to exchange (switch) with other verbs but not with nouns, nouns tend to exchange with other nouns but not with verbs, and so on. Such exchanges bespeak a syntactic (word order) level where grammatical class (e.g., verb versus noun) has functional importance and is not just the figment of some grammarian's imagination. It is thought that distinct levels of representation arise or are utilized during the process leading from thought to language production (Levelt, 1989).

Goal postures

Taking a cue from this kind of work, my colleagues and I have sought to elucidate the levels of planning for non-linguistic behaviours. The main contribution we have made is to suggest that there is a level of representation for motor planning between the identification of physical goals for movement and the planning of movements per se. This level of representation is the *goal posture*. The main idea is that when positioning movements are planned, as in directing one's hand to a target in space, a goal posture is planned before a movement to that goal posture is planned. The goal posture can be reassessed based on movement planning, so the process is not entirely unidirectional, but in the theory my colleagues and I have developed, it mainly is (Rosenbaum, Engelbrecht, Bushe, & Loukopoulos, 1993; Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995; Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001).

A goal posture is an intended body position. It includes the joint angles of all the joints in the body as well as the forces and torques of the body's muscles (or concomitant variables). Several lines of evidence have led to the view that goal postures, as just defined, are specified before movements are specified. Those lines of evidence will be summarized below, except for noting beforehand that an important clue about the validity of the posture-based motion planning view comes from dance. When dancers pirouette, they are instructed by their coaches to turn from one key position to another, directing their attention to a steady landmark in the external environment in successive spins (for a movement description, see Chapter 4 by Bläsing). When this method is implemented, the dancer looks as if he or she is spinning continuously, but from the perspective of the *control* of dance, what the dancer is actually doing is aiming for a goal position over and over again. Aiming for goal positions not only applies to pirouettes; it applies as well to other dance moves. Dance, for its appearance of being a *continuous* activity, is actually controlled, or is supposed to be controlled, by aiming for one target position after another. Insofar as this method is endorsed by dance coaches and proves useful for dancers, it probably reflects a deeper principle about the control of physical action. That deeper principle, according to the posture-based motion planning theory developed by my colleagues and me, is that a reference condition for goal postures is established for positioning movements before movements to those goal postures are planned.

What, then, are the arguments for the posture-based approach? One argument stems from consideration of the degrees of freedom associated with *positions* on the one hand versus *movements* on the other. The position of an object in three-dimensional space has six degrees of freedom: the x, y, and z values of its centre, and its pitch, roll, and yaw angles. The position of the human body, expressed in terms of joint angles, is the number of joint angle values required to uniquely characterize a posture. For the arm, this is seven: the shoulder has three degrees of freedom, the elbow has two degrees of freedom, and the wrist has two degrees of freedom (for a simplified arm model with only three degrees of freedom, see Chapter 3 by Cruse & Schilling, this volume). Other joints add still more degrees of freedom. When muscle force and torques are added, still more degrees of freedom are needed to fully characterize a posture. If *movement* is brought into the picture, still more degrees of freedom add to the mix. For movement, all the degrees of freedom for each posture on the way from the start posture to the goal posture must be added, plus the times of their occurrence come in as well. The number of degrees of freedom for an entire movement path is huge. The number of degrees of freedom for a single position, such as a goal position, is much smaller. This implies that it is easier to specify a goal posture before specifying a movement (compare this to the passive motion paradigm described in Chapter 3 by Cruse & Schilling, this volume).

Another reason why it makes sense to plan goal postures before movements is that in the case of positioning movements, the main task to be achieved is attainment of a position. For example, the task of touching an elevator button is defined with respect to applying an adequate amount of pressure at a location in external space. How one gets to the button is typically less important than pressing it. In terms of feedback control theory, the reference condition is closure of the button. This is the highest-level goal, in which case it makes sense that it should be the highest-level goal in motor planning. According to the posture-based motion planning theory, positioning movements are planned by first specifying goal postures that satisfy the requirements of bringing one or more parts of the body, or extensions of the body, to target locations. From among the possible postures that achieve this aim, the one that is chosen is the one that satisfies the most task constraints.

Those constraints range from those that are most important (e.g., touching the elevator button) down to those that are least important (e.g., moving the hand in a path of minimum curvature). The relative importance of the constraints can vary for different tasks. For example, the shape of the hand path may be relatively unimportant in an unoccupied elevator, but may be very important in an elevator that is occupied, especially if one of the other occupants is carrying a wet paint brush or a sharp, unsheathed sword. It might also be important in a dance movement in which the curvature of the hand path is exactly defined in order to elicit a specific impression.

According to the posture-based motion planning theory, goal postures are selected by finding postures that satisfy as many constraints as possible, and then selecting those postures that satisfy the most important constraints. The process of selecting the goal posture is achieved, in the theory, through a two-stage process. The first stage involves finding the goal posture from the set of recently performed stored goal postures that survives a winnowing procedure wherein each of the postures is accepted only if it satisfies successively lower constraints (Tversky, 1972). The second stage is a "tweaking" process in which the one accepted, previously adopted, stored posture is varied as time permits to allow for an even better satisfaction of the task requirements. Once goal postures are selected, movements to those goal postures are selected via the same constraint satisfaction scheme. If the movement selection process runs into problems given the goal posture that has been chosen at first, the goal posture may be reselected, thereby allowing for bottom-up as well as top-down control (see Rosenbaum et al., 2001, for details.)

The foregoing scheme is a typical memory-search and decision process within cognitive psychology. Accepting candidate stored postures based on how well they satisfy ever lower constraints is an example of a process known as *elimination by aspects* (Tversky, 1972). Here, candidates are rejected if they fail to satisfy the most important requirement, remaining candidates are rejected if they fail to satisfy the second-most-important requirement, and so on. If there is more than one remaining candidate at the end of the winnowing process, the choice is made at random. This method is familiar to anyone who has been involved in making hiring decisions, making mating decisions, or making shopping decisions. In making hiring decisions – say in deciding who to hire for a faculty position in a research-oriented academic department – highest priority is given to some area of research, second-highest priority is given to productivity, third-highest priority is given to teaching ability, and so on. Only if more than one candidate remains who satisfies all the main requirements can a preference be given for someone who happens to possess a fairly unimportant criterion, for example someone who also likes to spend one evening per week taking tango lessons just for fun. Elimination of aspects turns out to be an efficient means of choosing among alternatives when there are multiple constraints (Tversky, 1972).

The second step in the goal-posture selection process is also familiar in cognitive psychological models. Tweaking values – that is, injecting variations into candidate options – is often used as a memory search method and, relatedly, as a spur to creativity (this is illustrated for the process of choreography in Chapter 6 by Zöllig, this volume: "repeatedly trying out a movement in new ways until it fits"). Adding variations for the sake of achieving better fits is a well-known component of Darwinian natural selection.

Movies

These logical or principled reasons having been given for the posture-based approach, consider next how well the approach does in practice. In keeping with the idea that science has much to learn from the arts, it is relevant that the posture-based approach has long proven useful in the arts, or more specifically in animation. From the early days of generating animated cartoons, it was realized that the process of making such movies could best be pursued in a hierarchical fashion. At the highest level is the person or group of persons with the idea for the story line. At the next lower level is the person or group of persons responsible for generating key frames. At the lowest level is the person or group of persons responsible for connecting the key frames.

Key frames, as their name implies, are critical moments. For cartoon animators animating cartoon characters, and by extension for creatures animating their own bodies, for instance, in dance movements, these critical moments are goal postures (leaving out the outside events). Even if goal postures do not seem to be explicitly required (e.g., because there is no external target to which motion is explicitly required), they are essential for providing direction to the next lower level, to the production of movement. Without a key frame to which movement is made, it is well nigh impossible to know which of the infinite number of possible movements should be generated from the last critical position. By contrast and more positively, key frames provide rich information for movements. (This principle is also applied in a pedagogical concept presented in Chapter 7 by BenZion, this volume: the students first create a "shape bank" for postures or key frames, and then, in a second step, a "transition bank" for movements.)

Having key frames or goal postures makes it possible to transition between them with minimal path algorithms. Computer-based animation methods that rely on such algorithms yield convincingly realistic movement patterns. Furthermore, computer files that only store key frames and that are then read by programs that employ those minimal path interpolation algorithms (files in so-called .mpg format) take up much less memory storage than files that only store series of complete images (files in so called .avi format). It does not follow that if computers do well with .mpg files that biological animation relies on an analogous approach. However, the possibility is alluring. A number of lines of evidence, summarized below, support the idea that, in general, biological movement may be cognitively controlled much as computer animated .mpg files are.

Anticipation

One line of evidence bears out the expectation that if goal postures are represented in advance, features of movement to the goal postures should reflect anticipation of the goal postures' characteristics. Indeed, this is the case. Speeds of movements tend to grow with the distance to be covered, and this scaling of movement speed is manifest even within the first few milliseconds of movement initiation (Gordon & Ghez, 1994). This result suggests that the distance to be covered is known in advance. Directions of movement also differ right from the start of movement depending on where one is heading, and often in subtle ways. Brown, Moore, and Rosenbaum (2002) observed that when people began moving the hand toward a screen to place a hand-held object up against an image on the screen, the orientation of the object as it left the start gate was measurably different depending on which final orientation the hand-held object would have to occupy.

In reaching out to grasp an object, grasps reflect anticipation of future positions. For example, if a horizontal cylinder is grasped with the right hand and the cylinder will be turned 90 degrees *counterclockwise*, people show a strong tendency to grasp the cylinder with an *underhand* grasp. Such a grasp affords a comfortable or easy-to-control thumb-up grasp when the cylinder is brought to its terminal position. Conversely, if the same horizontal cylinder is grasped with the right hand and the cylinder will be turned 90 degrees *clockwise*, people show a strong tendency to grasp the cylinder with an *overhand* grasp. That grasp also affords a comfortable or easy-to-control thumb-up grasp when the cylinder is brought to its terminal position. This pattern of results – the so-called *end-state comfort* effect (see Rosenbaum, Cohen, Meulenbroek, & Vaughan, 2006, for review, and Weigelt, Cohen, & Rosenbaum, 2007, and Zhang & Rosenbaum, 2008, for later studies) – again suggests that advance information is available about how forthcoming movements will be completed.

Even at more macroscopic levels of behavioural description, one sees evidence for anticipation of future positions. Recent work in my lab has focused on the coordination of reaching and walking, two activities that have seldom been considered together despite the extensive body of research on prehension, on the one hand, and locomotion, on the other (Rosenbaum, 2008; van der Wel & Rosenbaum, 2007). When people decide between walking to the left or right of a table from which they are supposed to lift a bucket and carry it to a site varying distances from the left or right sides of the table, the participants are adept at selecting the side of the table that affords an expedient combination of walking and reaching. If the bucket is on the left edge of the table and requires a long reach from the right edge, participants will tolerate the long reach if it permits a short walk to the goal site. By contrast, if the bucket is on the left edge of the table and requires a long reach from the right edge, participants will not tolerate the long reach from the right edge if it requires a *long* walk to the goal site. In general, the likelihood that participants will walk along the left or right edge of the table to pick up a bucket on the left, middle, or right edge of the table depends on how far participants must reach relative to how far they must walk. The estimated cost of *reaching* over some unit distance, such as 1 metre, is about three times the estimated cost of *walking* over that same unit distance (Rosenbaum, 2008). The orderliness of the data and the data's susceptibility to a good fit with the model just sketched suggests that forthcoming movement sequences can be well represented in advance and that the entire body can be represented this way. This is what would be expected if goal postures play a role in movement planning.

Posture neurons

Another line of evidence for the representation of goal postures comes from neurophysiology. Graziano, Taylor, and Moore (2002) showed that sustained electrical stimulation of the motor cortex and premotor cortex in monkeys causes the monkeys to adopt characteristic postures, as would be expected if one subscribed to the functional reality of goal postures for motor control. Even when the monkeys were in different initial postures, the electrical stimulation elicited the same posture when the stimulation was applied at the same site. By contrast, when the stimulation was applied at different sites, different postures were adopted. The latter result indicates that different whole-body equilibrium positions are represented in the brain, as would be required if specification of goal postures were important for moving to goal postures.

Memory for positions versus memory for movements

If goal postures are more important than movements, one would expect memory for postures to be better than memory for movements. This prediction follows from research in cognitive psychology, where memory duration is often taken as a sign of the importance of coded experience. Memory for stories, for examples, tends to preserve the main idea in the story over the long term. Details such as the exact words used by the characters, the names of the characters, and so on fade much more rapidly. Information importance is not simply defined by information longevity, for that would be circular. Rather, information importance is defined by a range of factors such as how important the information is explicitly judged to be by the participants, how memory for one kind of information affects memory of another kind of information (higher levels should affect lower levels but not vice versa), and how long it takes to remember the information initially (more important information generally takes longer to remember initially than does less important information).

Consistent with the view that goal posture information is more important than movement information, it has been found in many studies that memory for position is better than memory for movement. For reviews, see Smyth (1984). For example, as shown by Marteniuk and Roy (1972), people have difficulty reproducing distances they have just covered, but they are adroit at reproducing final positions they adopted. The benefit of position memory over movement is not just because of better memory for extrinsic rather than intrinsic coordinates, for when body positions (postures) are experimentally dissociated from external locations, there is a clear contribution of posture memory per se (Rosenbaum, Meulenbroek, & Vaughan, 1999).

Simulation

The final source of evidence for the posture-based view is the ease with which movements can be simulated with it. With the theory, it is possible to simulate such activities as reaching for objects with straight-ahead movements, reaching for objects while circumventing obstacles, reaching for objects with hand-held tools, reaching at different speeds and using effectors in different ways to maximize biomechanical efficiency, handwriting, and compensating for changes in the mobility of different joints (see Meulenbroek, Rosenbaum, Thomassen, Loukopoulos, & Vaughan, 1996; Meulenbroek, Rosenbaum, Jansen, Vaughan, & Vogt, 2001a; Meulenbroek, Rosenbaum, & Vaughan, 2001b; Rosenbaum et al., 1995, 2001; Vaughan, Rosenbaum, & Meulenbroek, 2001, 2006; compare Chapter 3 by Cruse & Schilling, this volume). All of these simulation results are achieved with the concepts and methods outlined above. They are achieved by specifying goal postures that satisfy task constraints and then by specifying movements to those goal postures that satisfy task constraints. The quality of the simulations is judged by their visual similarity to observed behaviour and, in some of our studies, by the quantitative degree of fit to actually measured behaviour. Meulenbroek et al. (1996) pursued the data-fitting approach for handwriting, Meulenbroek et al. (2001a, 2001b) and Rosenbaum et al. (2001) pursued the data-fitting approach for hand and finger paths during reach-and-grasp moves, and Vaughan et al. (2001 and 2006) pursued the data-fitting approach for hand paths around obstacles, both in two-dimensional (planar) and three-dimensional (depth) tasks, respectively. All the comparisons were encouraging. In all cases, the simulated motions were as similar to actual behaviour of individual human participants as was the actual behaviour of the other human participants to the human data being studied. In other words, the model's fit to the behaviour of person A was no worse than the fit of the behaviour of person B to the behaviour of person A, and so on. Meanwhile, it was possible to reject versions of the model by using parameters that rendered it unlike what any person actually did. The latter outcome implies that the model was not simply too powerful to be rejected.

Conclusions

A few further comments are worth making about the simulation results that have been obtained and, indeed, about the status of the posture-based approach in general. First, although my colleagues and I have found the approach to be psychologically intuitive and powerful, it is not the only one there is, and it has limitations. Other theoretical approaches have been developed for the generation of movement patterns (e.g., Butz, Herbort, & Hoffmann, 2007; Cruse, Steinkühler, & Burkamp, 1998; Erlhagen & Schöner, 2002; Guenther, Hampson, & Johnson, 1998; Guigon, Baraduc, & Desmurget, 2007). Comparing the posture-based theory to these other approaches goes beyond the scope of the current chapter. However, the papers just cited, like the papers by my colleagues and me (Rosenbaum et al., 1993, 1995, 2001), have generally included comparisons of relevant theoretical positions, as all of us want for the responsible pursuit of scholarship.

Second and in the spirit of full disclosure, the posture-based approach has many limitations. The theory is not yet cast in neurally specific terms, it only handles moving with the body rooted to a particular place in the world (i.e., the model does not yet walk, let alone dance), it has limited learning abilities, and the model is entirely kinematic (i.e., it has not yet been extended to force and torque production). These limitations imply the need for caution in claiming that the approach is "the answer". In all likelihood, some idea or set of ideas from the approach will join with ideas from other models to permit a more comprehensive account.

A third comment concerns the simulation of dance. Dance has not been simulated with the posture-based theory, nor, as far as I know, has it been simulated with any other theory that generates movements on its own (autonomous motor planning). Artificial dancers have been developed in robotics, but they rely on observation of other dancers rather than autonomous generation of dance moves. The challenge in autonomous generation of dance is to get an artificial movement system, such as a robot, to dance in ways that are lifelike. This is a tall challenge, for it opens the domain of movement simulation from merely "getting the job done" to moving *stylistically*. Being able to move with different styles is likely to be a basic feature of motor control even though this has seldom been acknowledged in traditional, engineering-oriented research in this area. An animal or a person who needs to impress an antagonist with his or her seeming might, or who needs to impress a prospective mate with his or her suitability for parenting had better be able to move "in style". Dance can be viewed as a form of such stylized motor behaviour. The fact that ethologists speak of mating dances conveys this idea (see Brown et al., 2005). If we reach the point where we can get robots to dance as people do based on their own movement planning, this will indicate that we not only understand how to plan and control basic movements. It will also show that we understand how to plan and control the more nuanced features of movement that make activities like dance a natural activity for humans and animals, where the manner of moving as well as the sheer capacity for movement are equally important.

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3 Getting cognitive

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What do I see when I watch somebody dance? Obviously, a dance expert or a dancer would see the dance in a very different way than I do. Paying attention to the relevant features, he or she would be able to predict the next movements and therefore know where to look next and recognize a surprising move or a simple fault, whereas I only see a series of elaborate movements, surprised by their order and, it is to be hoped, pleased by their aesthetic expression.

But what do our brains see and do while watching dance? Is there any difference between the function of my brain and that of a professional dancer when going to the ballet? There is now a large amount of data supporting the notion that our brains process such visual experiences differently. In particular, studies of Calvo-Merino and colleagues (2005, 2006; see also Chapter 8 by Calvo-Merino, this volume) analysed activations in dancers' brains while watching familiar movements they could easily perform themselves, in contrast to equally skilled demanding movements used in a different style of dance they had never learnt. Major differences were found in brain activation while viewing these two kinds of movements. Our repertoire of movements and our abilities to act influence the way we perceive. This is in accord with many other neurological or behavioural studies (Fogassi, Ferrari, Gesierich, Rozzi, Chersi, & Rizzolatti, 2005; Jeannerod, 1999; Prinz, 1997) and the idea has been put forward that our own action system constrains our way of perceiving others' actions (Loula, Prasad, Harber, & Shiffrar, 2005; Schubotz, 2007; Schütz-Bosbach and Prinz, 2007). Observing a dance is activating the same neuronal circuits I would use to dance myself – I am dancing along in my head: perceiving is a way of re-enacting the watched dance.

In the following, we are going to elaborate on how a simple (re-)action system can become a system that perceives its environment in a meaningful way. We propose a very simple system that is limited to walking behaviour. With this example we want to demonstrate, on the one hand, how these simple control structures have to take into account the body of the walker and information about the environment and, on the other hand, how a body model can be used for perception and – as a next step by just decoupling the body and only acting on the body model – for planning ahead.

The details of the reactive system introduced here are based on insect studies. This is done for two reasons. First, because motor control of complex behaviours has been studied in insects in great detail on both the behavioural and neurophysiological level, and second, because there is evidence that the basic control structures of insects and mammals are comparable (Pearson, 1993). Any complex behaviour, including dance, does however not only rely on reactive structures, but includes higher-level, cognitive aspects like planning a movement or imagining a movement. Concerning such questions, the insect system is presumably not suited as a model. Therefore, in the second part of this chapter, we complement the reactive, low-level system with an expansion that covers cognitive aspects. This part is necessarily speculative, but still inspired by biological knowledge, and supports the idea that the cognitive system does not form a separate system independent of the reactive part, but relies on the reactive system by exploiting its properties.

This chapter is therefore to be understood as a short introduction to basic properties of motor control systems and as providing a description of one side of the bridge addressed by David Rosenbaum (Chapter 2, this volume) that may help to close the gap between science and art.

Motor control and cognition

In any organism, the basic task a brain has to solve is to control body movements. Some brains are, in addition, able to show cognitive abilities like thinking, imagining or feeling. Traditionally, questions related to how these different capabilities may be realized are considered to concern quite separate domains of research. However, more and more evidence has been collected – and we will argue along this line – that both aspects are not only tightly coupled, but may actually hardly be separable on the neural level. Both motor control and thinking (as well as imagining) appear to be produced by the same neuronal mechanisms, a finding that has great impact for the understanding of our brains.

The control of tasks like a cheetah chasing an antelope, a goat jumping on steep rocks, an octopus grasping a crab, or a spider spinning a web and later walking on it, is considered to be quite difficult. Nevertheless, the ability to cope with these tasks appears to be of quite different character compared to abilities underlying cognition, in particular human cognition that enables us to imagine future situations, to communicate using a complex language, to draw inferences and to find proofs for mathematical problems. Such cognitive tasks concern evolutionary inventions that are very recent (on an evolutionary time scale), and human beings usually feel privileged to have these capabilities available in contrast to other animals. Although it is not yet clear whether the "invention" of typical human cognitive abilities can really be considered an advantage in the long run – recall consequences of these capabilities such as the invention of nuclear technology, or all the still increasing ecological problems – to a scientist, cognition is quite an interesting phenomenon representing a challenge to understand the underlying principles. Trying to understand such underlying mechanisms by performing basic research can be considered progress with respect to our cultural development, but may also include applications like improved health care as well as, for the engineers, the construction of more intelligent machines – which, as a side effect, may in turn lead to a further increase of the man-made problems indicated.

As mentioned, we argue that the apparent gap between the two domains – motor control and cognition – is much smaller than usually assumed. To this end, we begin with a description of what we know about the control of movements, in particular of "simple" movements. By simple movements, we mean movements that are reactive or controlled by reflexes. The corresponding movement controllers may be learnt or may be innate, but in any case are characterized as representing a well-defined neuronal system that receives sensory inputs and uses these inputs to determine the motor output, like, for example, simple avoidance reflexes. As has been studied in insects, however, there might also be quite complex motor behaviours that still can be considered as sensory-driven or reactive.

Insect walking – although seemingly far away from human motor control, let alone from cognitive abilities – has been considered a typical case of reactive behaviour. Moreover, this behaviour has been investigated in some detail. We start by describing what is known concerning walking and climbing in insects. At first sight, the control of walking might appear to be quite a simple task. However, the control of walking includes many problems solved by nature that are apparently not understood by biologists and engineers. This is clearly illustrated by the fact that, although many six-legged, insect-like walking robots have been constructed (for an overview, see Berns, 2008), there is still a huge gap between the movements shown by these quite sophisticated robots and those of real insects. In the following we briefly address the questions of what is known about insect walking and what are still open questions (for further details, see Dürr, Schmitz, & Cruse, 2004).

An insect has six legs, each with three joints, therefore the movements of 18 joints have to be controlled simultaneously. When we consider each of these joints as a simple hinge joint (which is a simplification in some cases), each joint position can be characterized by one real value number defining the size of the angle of this joint. Thus, the central nervous system (CNS) of the insect has to specify 18 values in order to determine the position of the body in space. In other words, the CNS has to specify 18 *degrees of freedom*. So the question can be reformulated as: How does the CNS control these 18 degrees of freedom (joint angles) while the insect is walking? To describe a simple hypothesis concerning the neural system that controls movement of the legs, we have to refer to some details of the anatomy of the insect leg. An insect leg contains essentially three segments, the coxa, the femur and the tibia (Figure 3.1). The three hinge joints connecting these segments are correspondingly termed α joint, β joint and γ joint. To simplify matters, we

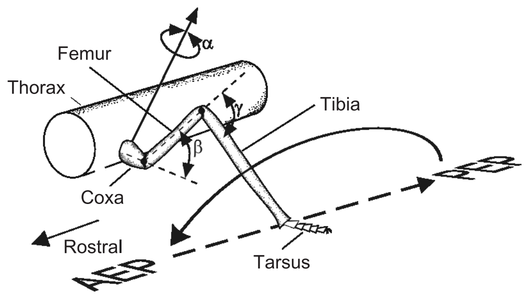

Figure 3.1 Leg morphology, leg angles, swing movement, stance movement (explanation in the text). AEP: anterior extreme position, PEP: posterior extreme position.

assume that each joint is controlled by one single information channel, the output value of a single "motor neuron" (this assumption is justified for a robot that has one motor per joint, but represents a simplification for animals that have at least two muscles per joint, each muscle usually being driven by many motor neurons.) In addition, each joint is assumed to be equipped with one sensor, measuring the actual joint angle. What would a neuronal system that controls sensory-driven movements look like? We begin with a simple behavioural element required for walking, the so-called swing movement.

A reactive system: Control of swing movement

When walking, a leg can be regarded as applying two behavioural elements alternately. The first is the *stance movement*, during which the leg supports the body while moving from front to rear in order to propel the body (during forward walking). Of course, there is a rear position of the leg, called the *posterior extreme position* (PEP), where the leg must be lifted off the ground and moved forward to start the next stance movement. This return movement starting at the PEP and ending at the *anterior extreme position* (AEP, see Figure 3.1) is called the *swing movement* (indicated by the curved arrow in Figure 3.1). Thus, the complete behavioural element requires lifting the leg off the ground, moving it forward, and then moving it downward in an appropriate spatial and temporal manner. What might a neural controller that is able to move the leg (i.e., the three leg joints), in order to perform such a swing movement, look like?

Before showing such a hypothetical controller based on a network consisting of artificial neurons, we are going to introduce our artificial neurons (Figure 3.2). A typical neuron consists of an input, the *dendrite*, a cell body, the *soma* (indicated by empty circles in Figure 3.2), and an output element, the *axon*. The output signal is transmitted to the input of the next neuron – its dendrite – via *synapses* (indicated by a small black circle in Figure 3.2). In the case of a motor neuron, the output signal drives the muscles (not shown). In

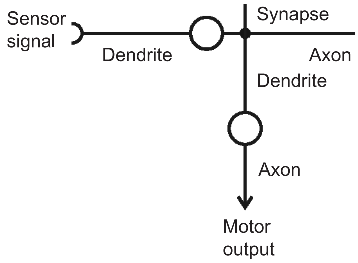

Figure 3.2 Connection between a sensor unit and a motor unit. Somata of the neurons are marked by empty circles, the connecting *synapse* is marked by a small black circle. The transmission of a sensor signal (input) is symbolized by a semicircle.

the case of a sensory neuron, the input is given by a physical measure (e.g., a leg joint angle) transmitted to an activation of the neuron. This transmission is symbolized by a semicircle in Figure 3.2.

Of course, in a realistic neuronal network, there is not just one sensor, one synapse and one output neuron, but many of each. Figure 3.3 shows a (still simple) network containing nine neurons. Three are motor neurons, which determine the motor output (α_m, β_m, γ_m) to the three leg joints, three are sensor neurons, which measure the actual joint angle values (α, β, γ). Three

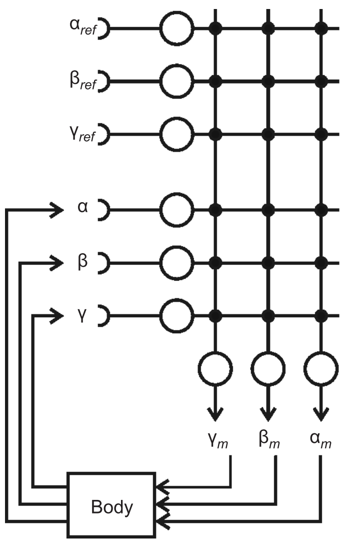

Figure 3.3 Swing net, controlling the swing movement of an insect leg (represented by the box "Body"). α_m, β_m, γ_m: motor output driving the three joints α, β, γ, the actual values of which are measured by sense organs. α_{ref}, β_{ref}, γ_{ref}: the angle values that should be reached at the end of the swing movement. Synapses are marked by closed circles (see Figure 3.2 for further explanations).

further neurons specify the angles (α_{ref}, β_{ref}, γ_{ref}) that, for each joint, should be approached at the end of the swing movement (we will later indicate where this information comes from) – representing a goal position, as described by Rosenbaum (Chapter 2, this volume). Now we have a network containing nine neurons connected by 18 synapses. Each synapse is characterized by a value that represents the strength of this synapse. This number represents a factor by which the signal coming from the axon of the first, presynaptic, neuron is multiplied before it is passed to the dendrite of the second, postsynaptic, neuron. Each dendrite simply sums all its input values. Having defined the structure of this net, the crucial question is: Can we find 18 values (synapse strengths) that, when this neural network is connected to a leg, drive a swing movement such as the one that can be observed in an insect?

The answer is yes, and therefore this network is called a *swing net*. With a specific set of synaptic values, this network, when activated, moves the leg up, forward and then down again. In this way, it produces a specific behaviour and may therefore be called a memory element that stores the knowledge as how to perform a swing movement.

Of course, further memory elements are necessary to control walking. First of all, each leg needs a *stance net* to be able to control the other important behavioural element, the stance movement. We will not describe the stance net in detail (see Dürr et al., 2004, for a simple solution, and Schmitz, Schneider, Schilling, & Cruse, 2008, for a more sophisticated version). However, given such a network, there is now a kind of competitive situation, because both networks, the controller of the stance movement and the controller of the swing movement compete to control the same joints; that is, the same motor output neurons. Therefore, a third neural network is required that decides which of the two behaviours, swing or stance, should actually be performed. This network is called a *selector net*. The selector net again receives sensory input on the basis of which decisions are made. For example, this input might concern the actual leg position or the leg having ground contact or not (the details of this selector net will not be explained here). Figure 3.4(a) schematically depicts these three networks plus a further one, called *target net*. The target net determines the position the leg should adopt at the end of swing (i.e., its goal position; compare Chapter 2 by Rosenbaum, this volume). This network receives sensory input from another leg, the anterior neighbour, in order to allow the swing net to move the swinging leg near the actual position of the anterior leg. This is quite helpful when climbing in branches, because the position of the anterior leg guarantees the ability to find support. All four networks mentioned receive sensory input from leg sensors; that is, from body parts that measure, for example, position and velocity, or ground contact of a leg (Figure 3.4(a), GC). In Figure 3.4(a) this information flow is depicted by the bold arrows pointing from the body to the sensory input of these networks. The swing net and stance net, in turn, provide motor output to move body elements; that is, leg segments (bold arrow pointing to "Body"). The ability of the selector net to decide between stance and swing is indicated by

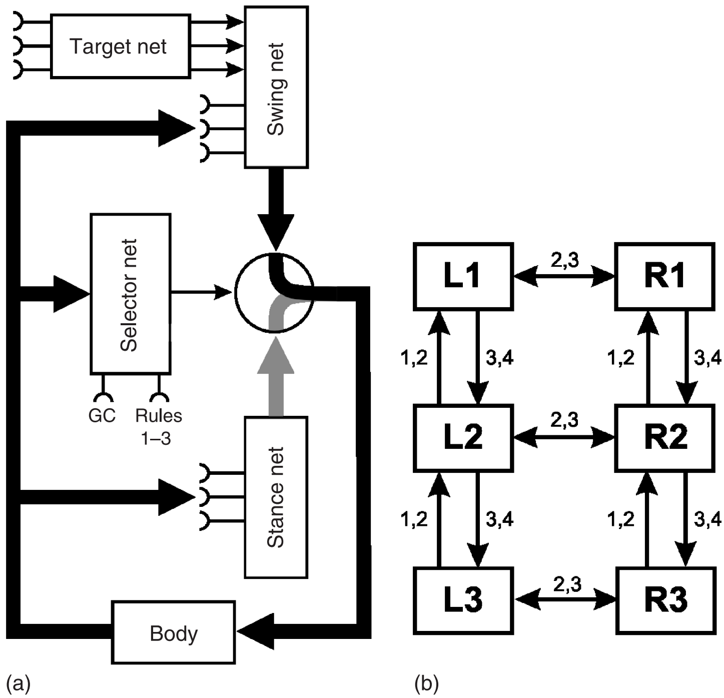

Figure 3.4 Walknet: (a) single leg controller, (b) coupling of the six legs. The selector net decides whether the swing net or the stance net can control the body (leg). The selector net receives as input whether the leg has ground contact (GC) or not as well as information concerning leg position, the latter signal being influenced by information from other legs (rules 1–3, see Dürr et al., 2004 for details). Numbers in (b) refer to these rules. Rule 4 is realized by the target net shown in (a).

the two arrows shown in black or grey, respectively. As our model has six legs, we need six of these controllers. Naturally, these six controllers have to be coupled to allow for coordination of leg movement during walking. Behavioural studies have indicated that a small number of local rules govern the coordination between the six legs (Dürr et al., 2004). Figure 3.4(b) illustrates the pathways of rules 1–4 acting between a pair of neighbouring legs each. As indicated, rules 1–3 influence the selector net. Rule 4 describes the effect of the target net.

Thus, Figure 3.4 depicts, in a graphical form, a quantitative hypothesis on how the neural system of an insect able to control walking might look. How can we show that this network, called Walknet, is actually able to control walking, in particular walking in a natural environment?

The only way to investigate and test the properties of such a model is to simulate it. This can be done in two ways. First, a so-called software simulation can be performed for which only a computer is needed. This type of simulation requires not only to simulate the network (in our case Walknet), but also to simulate the body and the environment, for example obstacles to be negotiated. Simulating the body (as indicated in Figures 3.3 and 3.4) and the environment in a physically realistic way is by no means trivial. In any case, such a simulation requires major simplifications. Therefore, a more realistic test for the hypothesis is to perform a so-called hardware simulation. This means that the neural network is still simulated on a computer, but instead of simulating the physical details of the body and the environment (e.g., slippery surfaces), a physical robot is used that acts in the real, physical world. In this way, the hardware simulation avoids errors due to inappropriate simplifications unavoidable by the above mentioned software simulations.

Walknet has been tested successfully by both kinds of approaches and has been shown to produce the different types of walking patterns observed in walking insects, to negotiate obstacles and curves, and cope with different disturbances (Kindermann, 2002). Simple expansions of the network allow coping with a loss of legs, as insects do (Schilling, Cruse, & Arena, 2007) and, in particular, climbing across very large gaps (Bläsing, 2006), the latter requiring complex searching behaviour as well as specific adjustment of leg stepping.

To summarize, quite complex behaviour can be controlled by a reactive, strictly sensory-driven neural network. Two aspects have to be emphasized. The network represents a completely decentralized structure. Apart from specification of the walking velocity and the tightness of a curve to be negotiated, there is no information from "higher" centres. All decisions are made locally, including the coordination between the six legs and the reactions to any unexpected disturbances. Thus, Walknet is an example of self-organization of complex behaviour. The second important aspect concerns the fact that the existence of the body (plus the environment) is an essential element of the "computation" necessary to control the behaviour. The movement of the individual leg is not only driven by its own muscles, but also by the influences of the other legs, to which this leg is mechanically connected via the body and via the various physical properties of the ground. This aspect is often characterized by the terms *embodiment* and *situatedness*, emphasizing the important contributions of the body and the properties of the environmental situation, respectively. Taking embodiment and situatedness into account allows for unexpected high "motor intelligence" in spite of a comparatively simple neuronal structure.

Eventually considered as a logical alternative to the reactive control structure advocated here, it has been stated that the basis of motor control relies on neuronal systems that form so-called central pattern generators or central oscillators; that is, systems that produce rhythmic motor output without need of sensory feedback (see Chapter 4 by Bläsing, this volume). This view is based on investigations that concentrated on fast walking or running. In such a centrally controlled system, small disturbances may indeed be compensated by exploiting passive, elastic properties of muscles and tendons (e.g., Blickhan, Seyfarth, Geyer, Grimmer, Wagner, & Günther, 2007; Pfeifer, Lungarella, & Iida, 2007). Generally, motor control programmes – innate or based on learning – that do not rely on peripheral feedback could be applied as long as the environment is highly predictable. Careful studies of animals walking slowly and in cluttered environments however show that sensory feedback is applied in these cases. Sensory feedback is also required for learning motor programmes. Therefore, both approaches are necessary, and it has been shown that there are control structures that allow a continuous transition between strictly reactive control and more centralized solutions (e.g., Cruse, 2002).

Cognitive systems: Why use internal models?

Understanding the control of motor behaviour being based on such simple, insect-like structures has been termed the behaviour-based approach. Proponents of this view (Brooks, 1991) have argued that the CNS does not require a representation of the body itself or the environment, as was typical for traditional artificial intelligence, but that, relying on embodiment and situatedness, the world as such can serve as "its own best model". This view was justified to oppose the strong influence of the later-termed "good old-fashioned artificial intelligence". On the other hand, an increasing multitude of experimental results clearly indicate that at least humans and other "higher" animals possess some kind of internal models of the world, including a model of their own body. The latter, seen from the brain's point of view, has been regarded the most important part of the world (Cruse, 2003). These results raise questions as to how such internal models (e.g., models of one's own body) might be realized neurally and what purpose such models may serve.

Regarding the question of what purposes internal models may serve, several answers are possible. One aspect is that knowledge about the geometrical properties of the body may be used to improve the quality of the sensory input. Sense organs, for example those monitoring the joint angles, always show limited accuracy of measurement. Therefore, it is possible that only incorrect information concerning the actual position of the legs and the body may be available, based on raw sensor data. In addition, the interpretation of these data may lead to geometrically inconsistent results (see the Pinocchio example below). However, running these partly incorrect data through such a body model can provide corrected sensor data. Such a body model could not only improve the sensor data, but may even restore information, if, because of defective sense organs, some data are completely missing.

A nice example showing that humans appear to apply body models for perception is given by Shiffrar (Shiffrar, 2001; Shiffrar & Freyd, 1990), whose experiments exploit the so-called phi phenomenon. When a subject is confronted with two successive images, for example one with a point on the left side immediately followed by one with a point on the right, we have the impression that there is only one point that moves from left to right. It is usually assumed that the brain constructs such an apparent motion along the shortest path between the two objects, which also produces the impression of reverse movement of the wheels of a stage coach in a Western movie, the so called wagon-wheel effect (see Purves, Paydarfar, & Andrews, 1996). Maggie Shiffrar confronted subjects with alternating pictures showing a person with two different arm positions (Figure 3.5). According to the apparent motion hypothesis, the arm should move along a straight vertical line as shown by the bold arrow. This was actually the case when both pictures were presented at a very short time interval. However, when this period was prolonged and corresponded to the time needed to move a real arm from the first position to the second, subjects perceived a movement as indicated by the curved arrow in Figure 3.5; that is, a movement that, in contrast to the result of the first experiment, could be performed by a human body.

These findings strongly suggest that the brain does not interpret the visual input at a "pixel level", but tries to feed it into its body model. If the match is sufficiently realistic, this interpretation is passed to the higher levels, leading to subjective experience. The result that the body model cannot match the very fast movements shows that our body models also represent some dynamic properties of the physical world. Possible brain sites involved in the recognition of biological movements are described in Chapter 9 by Cross (this volume), and sensorimotor principles underlying body schema are discussed in Chapter 10 by Jola (this volume).

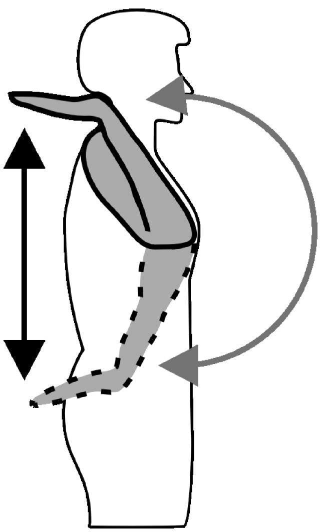

Figure 3.5 Shiffrar's experiment. Subjects are shown two pictures in temporal sequence, one with the arm in the upper position, the other with the arm in the lower position (dashed lines). For short delays an apparent motion is perceived as indicated by the black arrow, for longer delays the apparent motion follows the curved, grey arrow.

A second, and completely different, way to exploit a body model concerns motor control, in particular when the task is to control a body with extra degrees of freedom, which is the rule and not the exception. Think for example of the task to point with your hand at a dot marked on a table in front of you. The position of the dot in three-dimensional space can be described by three numbers, for example three coordinate values x, y and z of a Cartesian coordinate system. In other words, the task is defined by three degrees of freedom. However, the mechanics of the human arm are characterized by seven degrees of freedom, not counting the finger joints (see Chapter 2 by Rosenbaum, this volume, for a description of further types of degrees of freedom). Therefore, there are four ($7 - 3 = 4$) extra degrees of freedom, which allow for many different arm positions when solving the task. This has positive as well as negative consequences. It is positive because one can select a specific arm position that is more comfortable than others (see Chapter 2 by Rosenbaum, this volume, for explanations regarding the end-state comfort effect). It is negative because this situation requires the brain to solve a computationally difficult problem, so-called inverse kinematics. The solution is specifically difficult for the underdetermined case in which the brain has to select one of many possible solutions. However, if a body model is available, there is a comparatively easy way to solve this task. Intuitively, this solution has already been recognized by Heinrich von Kleist (1810) (see Box 5.1 in Chapter 5 by Puttke, this volume). In von Kleist's essay "On the Marionette Theatre", his protagonist, a ballet dancer, states that movements performed by puppets, simply moved by threads fixed to the hands, are comparable to animals or naturally moving humans regarding their elegance (see also Chapter 5 by Puttke, this volume). Von Kleist contrasts these natural movements assumed to be controlled by such a "puppet principle" with consciously controlled movements the actor vainly attempts to perform in an elegant way. Here we do not deal with the question as to how conscious control may influence the application of the body model.

In modern times, this principle has been termed the "passive motion paradigm" (Mussa Ivaldi, Morasso, & Zaccaria, 1988). The underlying idea is that the extra-degrees-of-freedom problem can be solved if a body model is used like a puppet: the tip of the puppet's or the body model's hand is pulled to the position of the target, whereby the other segments of the arm necessarily follow, thereby solving the problem. Rosenbaum (Chapter 2, this volume) refers to the same principle, stating that "it is easier to specify a goal posture before specifying a movement". To control the real arm, the joint movements of the model arm can be read off the model and then used as signals to control the real arm. Even constraints, such as mechanical limits of specific joints or information concerning more or less comfortable joint positions, can be introduced into the model. Therefore, it has been hypothesized (Steinkühler and Cruse, 1998) that body movement is controlled by application of a neuronal model of one's own body, which becomes particularly helpful when the body to be controlled contains extra degrees of freedom.

Dancers in some cases make use of the passive motion paradigm, when they optimize or improvise movements by imagining an impulse or force applied to a part of their body and then letting their body follow this imagined impulse or force.

A body model that can be exploited for perception and motor control may likewise be suited for the imitation of an observed movement, if activation of the motor output is not switched off (which is apparently the case for patients suffering from echopraxia). Perception, when directly connected to the motor control system, may immediately lead to understanding of the action observed, as perceiving that action means there is stimulation of the neuronal system that would be used when actively performing that action (e.g., Gallese and Lakoff, 2005; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; see also Chapters 8 and 9 by Calvo-Merino and Cross, this volume).

There is also another reason to use internal models. This aspect represents a crucial step beyond the capability of reactive systems as described so far. Internal models can be used to simulate a behaviour; that is, to test the possible consequences of a behaviour without actually performing this behaviour. For example, the walker may test whether it is possible to lift three specific legs without losing stability. To this end, the internal body model can be driven by the reactive controller while its connections to the motor output are switched off. The internally simulated behaviour of the body model provides sensory information back to the reactive controller as the real body does in a reactive system. Therefore the behaviour can be internally realized without harming the body, and even dangerous behaviours can be tested in this way. Thus, a system using such a body model is able to plan ahead, which, according to the definition of McFarland and Bösser (1993) can be characterized as being able to show cognitive behaviour. Sigmund Freud introduced the term "Probehandeln", an ability, which, according to Freud, corresponds to thinking. Of course, for such a system to be cognitive, further mechanisms are required, like the ability to judge the resulting outcomes of the simulated behaviour, and so deciding for or against it. This will not be discussed in this chapter, but solutions are presented by Schilling and Cruse (2008). The ability to simulate new movements may not only be exploited for testing new behaviours, but also for training specific movement sequences (see Chapters 1 and 5 by Schack and Puttke for examples of mental training). This may be advantageous as internal simulation can be faster and does not have to cope with unexpected disturbances or compensation for erroneous movements, as is the case when performing physical training in the real world. Because a body model that represents the physical properties of the real body in sufficient detail is required for such simulations, Metzinger (2006) used the term *second order embodiment* for this concept.

To study this application of a body model in more detail, we have to return to the first question mentioned above, the question of how such a body model could be realized by means of a neuronal network. Recall that this body model must not be a static model in the form of a look-up table, but has to be "manipulable" like a real puppet. This means that it, like the puppet, must be able to represent all geometrically possible body positions and movements.

A concept for the construction of such a body model has been proposed that is based on a specific *recurrent neural network* (RNN) (Steinkühler and Cruse, 1998). To allow the reader to develop an intuitive idea of the functional properties of such recurrent neural networks, the basic principle will be explained using a simple version (Kühn, Beyn, & Cruse, 2007). Consider three vectors ***A***, ***B***, and ***C*** forming a triangle (Figure 3.6(a)). Vectors ***A*** and ***B*** may be interpreted as describing the upper arm and the lower arm, respectively, while vector ***C*** points from the basis (the shoulder) to the hand. This geometrical arrangement can be represented by an RNN as shown in Appendix 3.1 of this chapter in more detail.

This network is depicted graphically in Figure 3.6(b). Each artificial neuron, or unit, receives an input from sense organs (left semicircle), and shows an output as is the case for the neurons shown in Figures 3.2 and 3.3. Different to these earlier networks, each neuron also receives input from the other neurons belonging to this network and from its own output (recurrent input, right), thus forming a recurrent net. As indicated in Figure 3.6(b), a recurrent network with n neurons contains n^2 synapses (see Appendix 3.1). What are the properties of such a network? At the beginning, the activations of the three neurons are set by the sensory input given for one iteration. If this input value describes a geometrically consistent situation (i.e., a closed triangle in Figure 3.6(a)), the activation of the net remains stable, even after this input is switched off. This means that such a network represents a memory for the actual position of the arm. An important property of this network is that, after any disturbance given at the input, the network always relaxes to a new stable state that is again characterized by a geometrically sensible position of the arm. This means that the three vectors again form a closed triangle, in general different from the first triangle. In this way, the network is able to represent geometrically possible body configurations. The sensory (e.g., visual) input describing vector ***C*** sets the status of the network; that is, determines the position of the arm segments, and the output drives the

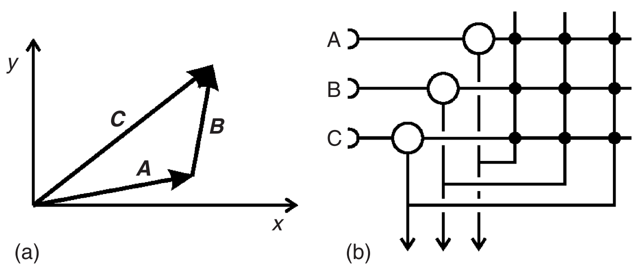

Figure 3.6 (a) Three vectors that represent a two-segment arm (vectors ***A*** and ***B***) that points to a position determined by vector ***C***. (b) An RNN structure that can represent all possible vector positions (see Appendix 3.1 for details).

muscles or motors controlling the joints to adopt the corresponding position of the arm. To control a movement of the arm, this net could be exploited in the following way. If the input to neuron C is changed, for example by a spoken command ("move the hand to the dot"), vector ***C*** is changed – it now points to the target position – and, as a consequence of the recurrent connections, the vectors ***A*** and ***B*** are changed, too, until they fulfil the geometrical condition determined by the externally determined vector ***C***. These changes in the model can be used to move the joints of the real arm. Thus vector ***C*** plays the role of the thread pulling the hand of a puppet.

Another interesting property of these networks is the following. The individual neuron, being part of a recurrent network, cannot be classified as either a sensory unit or a motor unit as was still possible in the example of the feed-forward network above (Figure 3.3). This is reminiscent of the properties of canonical neurons or mirror neurons, found within the premotor cortex of monkeys and described by Rizzolatti et al. (1996) as well as Gallese and Lakoff (2005). Mirror neurons display a somewhat unexpected property. They are active when the animal performs a specific movement, but also when the animal observes the same movement being performed by another subject (see Chapter 8 by Calvo-Merino, this volume). Thus they appear at the same time to be both motor-related and sensor-related, which is the case for the units of our RNN as well. Thus, observation of the body movement of another subject and controlling the corresponding movement of one's own body appear to be performed by one and the same neural correlate. Together with Shiffrar's result reported earlier, suggesting that perception of a body movement of another person requires a neural body model (Figure 3.5), this leads to the speculation that mirror neuron- and canonical neuron-like units are part of this body model and that it is not only used for perception, but also for controlling the movement of one's own body. This also agrees with the result that video recordings of movements of one's own body can better be recognized than movements of other human subjects (Loula et al., 2005).

A functionally very similar model has been proposed by Rosenbaum (for references see Chapter 2 by Rosenbaum, this volume). Both models are able to deal with extra degrees of freedom. The most important difference between the models refers to the fact that our model is based on an RNN structure that determines the position dynamically, whereas the model proposed by Rosenbaum uses look-up tables that can be learnt.

In the remainder of this chapter, we briefly indicate how these ideas could be implemented in order to expand a reactive motor system, for example Walknet, to become a cognitive system; that is, a system with the capability to plan ahead. Figure 3.7(a) shows an abstracted version of Walknet as sketched above (the fact that there are many leg controllers is indicated here by showing stacked swing nets and stance nets). The motor output drives the body, which, by influencing the sense organs, closes the loop and stimulates the neurons of Walknet, allowing for complex behaviours. In contrast to this

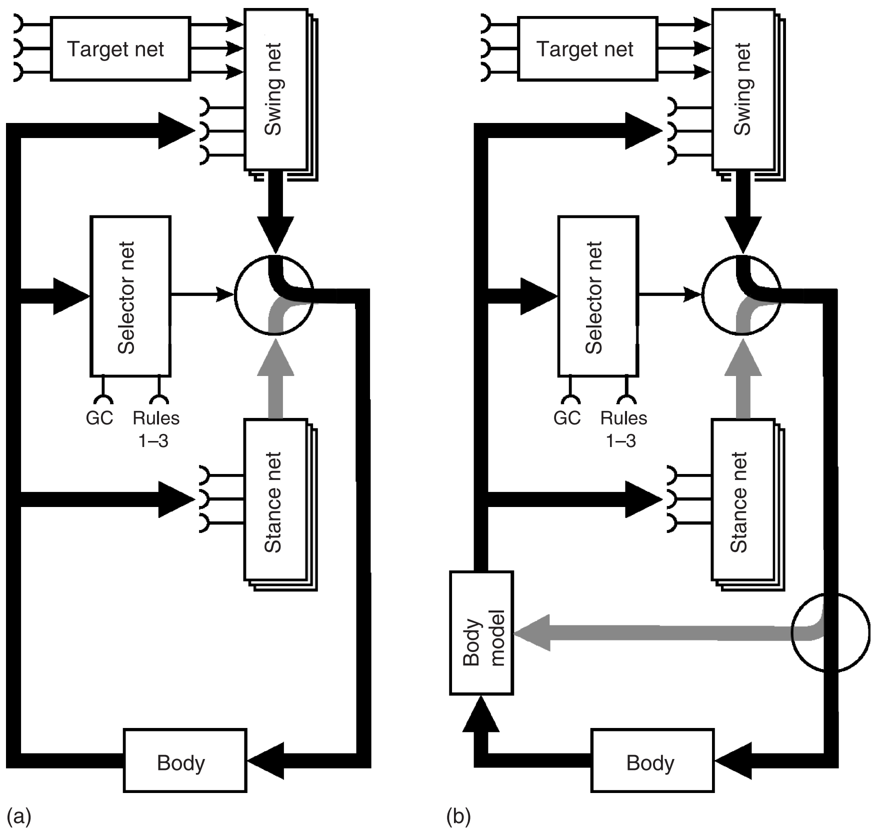

Figure 3.7 (a) Walknet: the fact that there are six leg controllers is indicated by plotting several stacked stance nets and swing nets. (b) Expansion of Walknet by introduction of a body model. A switch (circle, lower right) is introduced to decouple the controller from the motor output to the body and drive the body model, instead.

basic version, the sensory input is already provided to a body model to improve perception as described earlier. Figure 3.7(b) shows a further expansion. A switch (circle, lower right) is introduced that allows to direct the motor output either to the body or, instead, to the body model. The latter allows for a simulation of body movements. We assume that the switch is triggered in "emergency" situations, when a situation has occurred that cannot be handled by the reactive controller. Specific emergency sensors are, of course, required to identify such a situation. To be able to plan ahead, the system is further equipped with the ability to invent new behaviours that then can be tested using this body model. If by such simulations a solution is found that does not activate the emergency sensors anymore, this solution appears to be a sensible one that should therefore be tested in reality. This requires the switch to be moved back into its original position. In addition, this new solution, if really successful, should be stored in long-term memory for later use. This concept, representing a realization of more general ideas proposed by different authors, for example the *simulation theory* by Jeannerod (1999), or the *common coding concept* by Prinz (1997) (see also Chapter 8 by Calvo-Merino, this volume), is actually being tested by expanding Walknet to CogWalker as indicated.

Internal aspect

In the preceding sections we have considered neuronal mechanisms that might, hypothetically, be responsible for the control of reactive behaviour and for the control of cognitive behaviour. However, concentrating on the neuronal mechanisms we have completely neglected an intriguing aspect. This concerns that fact that some neural activities lead to the phenomenon of subjective experience whereas others do not.

An exciting example is given by a masking experiment investigated by Ansorge, Klotz, and Neumann (1998). A subject has learnt to press a button as fast as possible with the right hand when a square is presented on a screen, and to press a different button with the left hand when a circle is shown. In the crucial experiment, after learning is finished, the circle is shown, but only for about 30 ms, and is then followed by a square shown for a longer time. Interestingly, the subjects report to have seen the square only, but nevertheless press the left button belonging to the circle. Thus, the square was subjectively experienced, but not the circle, although the latter stimulus has triggered the relevant neuronal system leading to a behavioural reaction.

The phenomenon of some neural activities leading to subjective experience raises questions on quite different levels, a comparatively easy one concerning the anatomical and physiological properties of those neural networks that lead to subjective experiences or do not, but also to a second, much more difficult question. How can we, or can we at all, understand that a neuronal (i.e., physical) mechanism creates, or is paralleled with, such a "miraculous" property as subjective experience? This question is directly related to the mind–body problem, and some philosophers even assume that finding the answer to this question is beyond human capabilities. Chalmers (1996) has called this the "hard problem".

Concerning the first, much simpler, question, finding sensible answers might be possible. Different observations support the assumption that some activities of certain as yet unknown neural networks form at least the necessary conditions for subjective experience to occur. It is, for example, clear that the naive assumption "we experience what our sense organs provide" is not justified. We do not perceive the image projected to our retina, but a much more elaborated image, which means that at least some neuronal computation is required before a state is reached that allows for subjective experience. Furthermore, patients with an amputated arm often report subjective experiences of this missing arm, so-called phantom-limb sensations. (In some cases, such phantom limbs have even been reported by persons who were born without the limb in question.) This observation shows that sensory input is not necessary for subjective experience. Investigation of patients suffering from hemi neglect syndrome who, after specific brain damage, experience only half of the world in their view, although their sensory systems are intact, may provide hints to the neuronal structures that are responsible for subjective experience.

Imaging studies and other experiments strongly suggest that the same neuronal systems are responsible for the control of action, action planning and imagining actions (e.g., Gallese & Lakoff, 2005). These results have led us to the speculation that the RNNs suggested above to represent the body models required for control of action and for planning ahead, also form the neuronal substrate that is the prerequisite for our capability to have subjective experiences. This assumption has led Metzinger (2006) to the notion of *third order embodiment*. Cruse (2003) has specifically speculated that the phenomenon of subjective experience occurs when the corresponding RNN is close to the end of its relaxation. According to this hypothesis, the RNN approaching its attractor state might be the necessary and sufficient condition for subjective experience.

At first sight, a test of this hypothesis appears to be impossible, because we cannot decide whether a neural network constructed according to the hypothesis actually creates subjective experience. We can only register subjective experiences by introspection or by relying on reports of other human subjects. Nevertheless, an indirect approach appears to be possible. Basically, the idea to test this hypothesis is to search for artificial neural networks that can simulate the observed behaviour and approach an attractor state when, in the corresponding experiment with humans, the latter report to have the corresponding subjective experience. We have actually done this for the masking experiment explained above. In principle, such a simulation is also possible for another exciting experiment, the so called Pinocchio illusion (Lackner, 1988). In this experiment a person is asked to hold his or her nose between the index finger and thumb of the right hand. Then the biceps muscle of the right arm is mechanically stimulated with a high frequency signal. This stimulus has the effect that the subject has the impression that the elbow joint is extended, although it does not move at all. During this treatment, some subjects have the subjective experience that their nose is elongated, up to 30 cm (hence the name "Pinocchio illusion"). Elongation of the nose may actually occur in the body model proposed (Schilling & Cruse, 2008) when the attractor state is being reached.

Another famous experiment, reported by Ramachandran (Ramachandran, Rogers-Ramachandran, & Cobb, 2002), may also be explained this way. A patient suffering from a phantom sensation of the amputated left arm felt this arm to remain always in a fixed position. Ramachandran placed a mirror before the patient so that the mirror image of the patient's right arm appeared at a position where the intact left arm would have been. The patient now saw two arms, but still felt his left (phantom) arm in the usual position. Now Ramachandran asked him to move both arms in the same way. Although the patient first responded that he had not been able to move his left arm for many years, he followed the request and reported excitedly that suddenly he felt his left arm moving. This subjective experience disappeared when the mirror was taken away. According to our interpretation, the patient's body model received new sensory (visual) input, which stimulated the arm model to match the external stimulus (corresponding to the ***C*** vector in our model shown in Figure 3.6). Approaching this new attractor state also led to the corresponding subjective experience.

So, for all three examples, the behaviour of the artificial network is in agreement with the behavioural observations and with the report of subjective experiences, thus supporting our hypothesis. For a way to cope with the difficult question mentioned above, Chalmers' "hard problem" (see Cruse, 1999, 2003), in short, we have argued that this question will not be explicitly answered, but will simply disappear instead. This will happen just in the same way as was the case for a question intensively discussed at the beginning of the last century: Is there a specific entity that causes a physical system to become a living one? Today it is generally assumed that there is no necessity for such an entity as a *vis vitalis*. Rather, the state of being alive is considered a system property.

Conclusion

In summary, results of a broad range of experimental investigations and of simulation studies support the idea that human brains contain neural networks that are simultaneously responsible for motor control, perception of movement, imitation, planning movements and imagining them (see also Chapters 8 and 9 by Calvo-Merino and Cross, this volume). The ability to plan ahead characterizes a system as a cognitive one, and the ability to imagine refers to the phenomenon of having subjective experience, eventually also considered as an essential prerequisite for a system to be termed cognitive. Neural network simulations that we perform to understand these capabilities are based on a body model using a specific RNN, the units of which show functional resemblance to mirror neurons. The internal body model is assumed to be used for perception, in particular for correction of partly incorrect or replacement of missing sensor data, but also for understanding the meaning of observed actions as well as for motor control, motor imitation and motor planning ("probehandeln"), the latter three relying on the "passive motion paradigm", or "von Kleist principle". According to this principle, movement control (in particular when extra degrees of freedom have to be controlled, which is the case in almost all movements of the human body) corresponds to moving a puppet by pulling an imaginary thread. The passive motion paradigm is also of practical value for dancers, as it is applied in many situations for generating and controlling movements in dance. Even though our network model shows a relatively simple structure, it nevertheless allows for an interpretation of how subjective experiences may evolve.

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Appendix 3.1

As mentioned in the text referring to Figure 3.6(a), the vectors $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{C}$ are considered, with $\boldsymbol{A}$ and $\boldsymbol{B}$ representing the upper and the lower arm, respectively, and $\boldsymbol{C}$ the connection between the shoulder and the tip of the hand. How could such a situation be represented by a neural network? This geometrical situation can be described by the vector equation $\boldsymbol{A} + \boldsymbol{B} = \boldsymbol{C}$. This equation can be used to determine the following system of equations:

$$\boldsymbol{A} = -\boldsymbol{B} + \boldsymbol{C}$$

$$\boldsymbol{B} = -\boldsymbol{A} + \boldsymbol{C}$$

$$\boldsymbol{C} = \quad \boldsymbol{A} + \boldsymbol{B}$$

If we consider these vectors as time-dependent variables – necessary for example because the position of the arm may vary over time – the system can be reformulated as:

$$\boldsymbol{A}(t + 1) = -\boldsymbol{B}(t) + \boldsymbol{C}(t)$$

$$\boldsymbol{B}(t + 1) = -\boldsymbol{A}(t) + \boldsymbol{C}(t)$$

$$\boldsymbol{C}(t + 1) = \ \boldsymbol{A}(t) + \boldsymbol{B}(t)$$

which can further be expanded by introduction of a factor $d \geq 0$

$$\boldsymbol{A}(t + 1) = (d^*\boldsymbol{A}(t) - \boldsymbol{B}(t) + \boldsymbol{C}(t))/(d + 1)$$

$$\boldsymbol{B}(t + 1) = (-\boldsymbol{A}(t) + d^*\boldsymbol{B}(t) + \boldsymbol{C}(t))/(d + 1)$$

$$\boldsymbol{C}(t + 1) = (\boldsymbol{A}(t) + \boldsymbol{B}(t) + d^*\boldsymbol{C}(t))/(d + 1)$$

This equation system describing the temporal change of vectors $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{C}$ can be split into two systems of equations each describing scalar values, the x-components and the y-components of the corresponding vectors. As the coefficients are the same for the x-component system and the y-component system, only the x-system will be shown.

$$\boldsymbol{A}x(t + 1) = d/(d + 1)^*\boldsymbol{A}x(t) -1/(d + 1)\ ^*\boldsymbol{B}x(t) + 1/(d + 1)^*\boldsymbol{C}x(t)$$

$$\boldsymbol{B}x(t + 1) = -1/(d + 1)^*\boldsymbol{A}x(t) + d/(d + 1)^*\boldsymbol{B}x(t) + 1/(d + 1)^*\boldsymbol{C}x(t)$$

$$\boldsymbol{C}x(t + 1) = 1/(d + 1)^*\boldsymbol{A}x(t) +1/(d + 1)^*\ \boldsymbol{B}x(t) + d/(d + 1)^*\boldsymbol{C}x(t)$$

The coefficients of this system, describing the matrix:

$$d/(d+1) \ -1/(d+1) \ 1/(d+1)$$

$-1/(d+1)\ d/(d+1)\ 1/(d+1)$

$1/(d+1)\ 1/(d+1)\ d/(d+1)$

can be interpreted as representing the strengths of the synapses of the RNN. These synapses are shown in Figure 3.6(b) by small closed circles in the same format as given by the matrix. The output values for time $t + 1$ are used as input to the next iteration, thus forming a recurrent system.

This network shows the properties mentioned earlier. By changing the input (vector ***C***), the output of the units representing vectors ***A*** and ***B*** can be used to control the movement of the arm to the new position. As the network can easily be expanded to represent limbs with more joints, such a system with extra degrees of freedom allows for an infinite number of solutions (arm positions) when pointing to a given position in space. The simple network introduced here is, however, not able to maintain a constant length of a vector representing a body segment. To represent a realistic body with fixed segment lengths, more complex networks, the so-called MMC nets with nonlinear expansions, are necessary (see Steinkühler and Cruse, 1998).

4 The dancer's memory

Expertise and cognitive structures in dance

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Dance as embodied cognition

In the course of evolution, a large variety of bodies and nervous systems have come into existence, each of them adapted to and optimized for its own natural environment, or ecological niche. As different environmental conditions necessitate or favour different ways of moving, the range of motor systems evolved is as vast as the range of environmental conditions that can be encountered on earth. Locomotion of an organism that merely performs a small number of behaviours, like moving from one place to the other to forage and flee from enemies, might be based on a very simple control system. Biologists have hypothesized that the walking behaviour of an insect could easily be controlled by a system that lacks a central control unit or brain that mediates the synchronization, provided each of the six legs is controlled by a local module (see Cruse et al., 2004). Instead, the direct coupling of the legs through the body and the environment, as well as their interconnection through some local coordination influences, is sufficient to cause stable and adaptive gaits. With such a simple control system, the animal would be able to walk and master obstacles of notable size (Bläsing, 2006; Bläsing & Cruse, 2004). It could live successfully as long as its environment did not provide too many changes that called for intensive problem solving. Building a computer simulation of such a system is a complicated, yet solvable, task, as has been demonstrated by Cruse and Schilling (Chapter 3, this volume). Similar results have been obtained by scientists who have built models of the motor systems of amphibians, such as salamanders (Ijspeert, 2001), which basically consist of different sets of neural oscillators for cyclic movements coupled with each other in such a way that different types of locomotion emerge – as in the salamander, swimming and walking. Such basic types of locomotion are essential prerequisites for more complex behaviours (see Chapter 3 by Cruse and Schilling, this volume). In the real world, even amphibians do more than move from one place to another. If we regard, for example, a frog catching a fly, it becomes clear that cyclic movements are not sufficient for such behaviour. In this case, discrete, goal-directed movements are needed that are controlled by a system that monitors the stimulus, in this case, the fly (see Arbib & Liaw, 1995). The endeavour to model such movements has given birth to the idea of schemata, conceptualized as functional units of motor behaviour and corresponding perceptual processes, including their neural correlates (see, e. g., Arbib, Conklin, & Hill, 1987).

As a result of the complexity of the natural world, organisms have evolved that can adapt quickly to new situations, remember what has happened in the past, infer from past experiences what might happen in the future, and use what they have learnt to plan their future actions – in short, act in a cognitive way (see McFarland & Bösser, 1993). Cruse and Schilling (Chapter 3, this volume) have illustrated how a cognitive system might evolve from a simply reactive one. The evolutionary perspective suggests that cognition and physical configuration depend heavily on each other. A sophisticated control system cannot evolve without a body through which it can interact physically with this environment, and a moving body can only realize the degrees of freedom its control system allows for. Internal representations co-evolve together with corresponding actions, and become vehicles for higher mental functions such as thinking and planning ahead (see Steels, 2003). Gilbert and Wilson (2007, p. 1352) have stated that "the mental representation of a past event is a memory, the mental representation of a present event is a perception, and the mental representation of a future event is a simulation." The view that a mind, or a cognitive system, can only evolve through the interaction with the physical world has been termed "embodiment" (see Metzinger, 2006; Schilling & Cruse, 2008; Wilson, 2002; Chapter 3 by Cruse & Schilling, this volume), and has been discussed intensively among scientists in recent years. Other perspectives have been put forward mainly in the field of artificial intelligence (see, for example, Bach, 2009), however, this line of thought will not be elaborated here, as for our topic the body is a crucial prerequisite. For dancers, the idea that thinking, understanding, and learning begins with the body is not at all astonishing. How should it be otherwise? This is, in my view, one of the reasons why the art of dance and cognitive science can form a very fruitful alliance.

Why study mental representations of movement?

A behavioural scientist who observes the movement of an animal, for example of a stick insect climbing across a large gap (see Figure 4.1), is often confronted with a broad range of different things happening at the same time, such as different body parts moving in different directions, their speed changing constantly, and coordination arising somehow miraculously to make the parts contribute to the whole.

If the scientist wished to analyse the movement of this insect, he or she would have the choice of numerous parameters to measure (e.g., joint angles

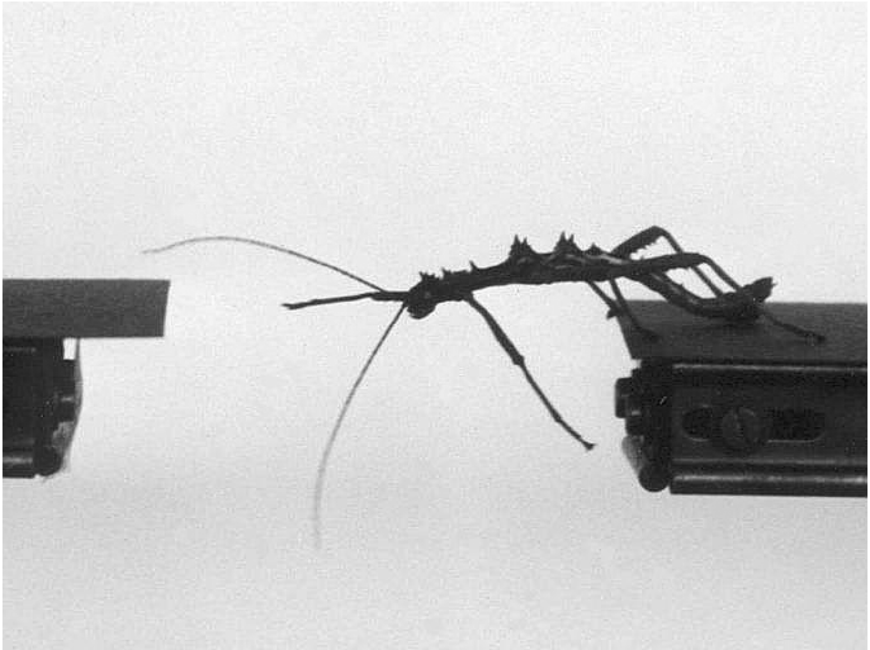

Figure 4.1 Stick insect crossing gap. The stick insect *Aretaon asperrimus* is beginning to climb across a gap of 5 cm width (approximately the insect's body length), using its feelers and front legs as probes. These insects from Borneo cannot jump or fly, and therefore have to rely on their ability to climb over obstacles when foraging on the leaves of shrubs and small trees (modified from Bläsing & Cruse, 2004).

and the way they change over time, forces, muscle contractions and the firing of nerve cells, etc.). If the movement sequence were fairly complex and the goal of the scientist was to understand its structure and the way it is embedded into its context, it might be a good choice to start by dividing it into different parts, into building blocks that can be easily recognized. Behavioural scientists call such a list of building blocks an ethogram. An ethogram consists of a list of behavioural elements that add up to the behaviour in question, described on an observable level. By defining functional subtasks, such as partial movements performed by different body parts, the whole movement can now be analysed and described in terms of its architecture (i.e., the way it is built up from these building blocks). Additionally, the occurrence of the building blocks and their mutual relations can be quantified to deduce their functional roles. From a quantitative analysis based on an ethogram, a flow chart like the one in Figure 4.2 can be drawn to illuminate the relations between the building blocks, thus illustrating how the behaviour is structured (Bläsing & Cruse, 2004). The resulting movement description is not as comprehensive as one that takes into account all joint angles and their changes

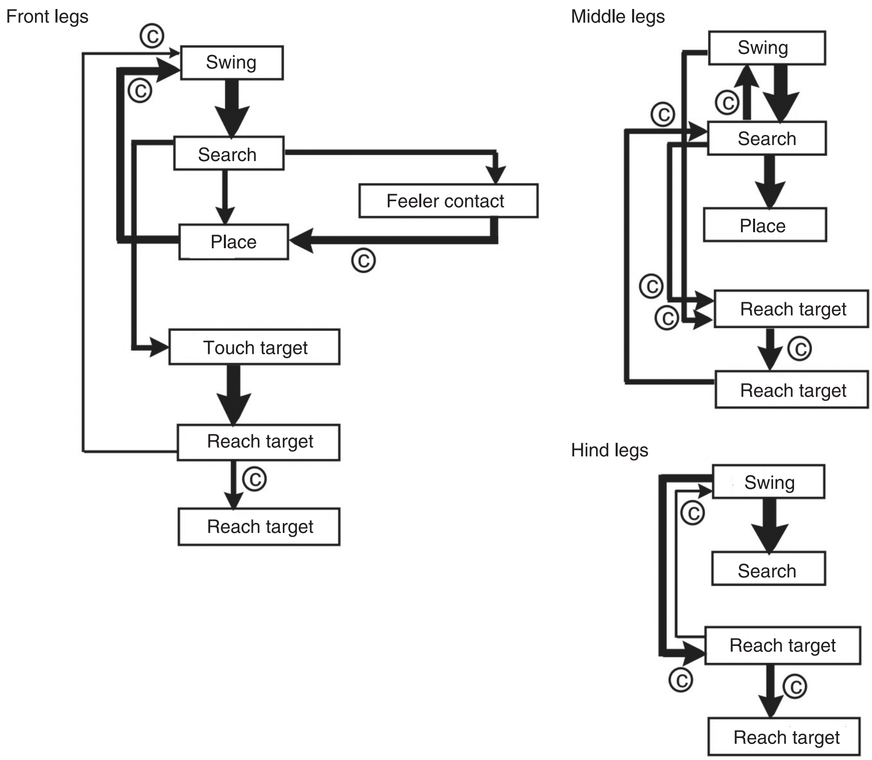

Figure 4.2 Flowchart of an insect gap-crossing sequence. The behavioural sequence is separated into the front leg, middle leg and hind leg sequence, which hardly overlap. The size of the arrows indicates the frequency of the observed behaviours, and "c" indicates a change to the contralateral leg (i.e., the leg on the other side of the same body segment). The ethogram used here consists of the following elements: swing – the leg is lifted from the ground and moved forward; search – the leg is moved in loops in an explorative manner in order to find new ground; place – the leg is placed back on the ground approximately where it was placed before; touch target – the leg touches the ground on the other side of the gap; reach target – the leg is placed on the ground on the other side of the gap; feeler contact – the feeler touches the ground on the other side of the gap, providing the insect with information that there is ground ahead (modified from Bläsing & Cruse, 2004).

over time, let alone neural firing patterns; however, it enables the scientist to understand the movement structure on a functional level, and compare it to similar movements that might arise under slightly different conditions without losing the overall view of the movement and its context.

Beyond what has been said so far, if the scientist wants to further examine the structure of the observed movement, s/he has different options. First, the scientist could decide which small sections of the movement are of special interest, taking into account all the information gathered about the overall behaviour, and investigate, for instance, the searching trajectories of a single leg or feeler, describing the course of its joint angles over time under varying conditions. The scientist could also study the insect's nervous system to find out how the specific movements are controlled on the neuronal level. Finally, if the scientist wanted to get an idea of the completeness and consistency of the assumptions drawn from the results, s/he could run a computer simulation and compare the outcome with the biological data. What the scientist cannot do, however, is simply ask the animal how it controls the movement deliberately, and how its movements relate to its intentions and experiences. Even if the animal in question is a human, the answers to the questions would be hard to come by. As humans, we have inherited many different ways of moving and interacting with our environment. At some point in evolution, we have acquired the ability to move in a deliberate and rhythmic way, to communicate and express emotions and ideas through our body, to mimic and imitate the movement of other humans and animals, and to assign abstract qualities like beauty to such movements. We have learnt to use these exceptional abilities to tell stories, and we have started to create movement styles just to serve this purpose. In short, unlike all other animals, we have learnt to dance!

We are now leaving other animals behind and focusing on humans in particular. When we study complex movements in people we gain access to the same levels of movement analysis as in the behavioural study of animals. This can be done for instance by observing the kinematic features of movement via motion capture, measuring the activations of muscles via EMG, or by recognizing the movement-related activity in the central nervous system, applying methods such as EEG, fMRI or PET (see Box 4.1). These methods have also

***Box 4.1* Methods in brain and movement science**

Electroencephalography (EEG) is a method of recording the activity of neurons, mainly in the cerebral cortex, using a set of electrodes placed on the scalp. Potentials of single neurons are summed, and the resulting brain waves can be used to monitor the activity of the cortex over a longer period of time, or to measure evoked potentials that occur in response to specific events. In studies of cognitive science, event related potentials are recorded, for example, to gain information about the processing of distinct signals in the brain (e.g., following the perception of unfamiliar words, pictures or sounds). The study of brain waves is an important measure in sleep research and neurological diagnostics, as different states of sleep, alertness or attention are characterized by brain waves of specific frequencies and amplitudes. Another important field of application is clinical diagnostics, as several neurological diseases (e.g., epilepsy) can be identified on the basis of specific brain wave patterns.

Electromyography (EMG) is a method of recording the activity of muscles, usually using surface electrodes fixed on the skin above the muscle. Muscle activation is generated by electric potentials from nerve cells (motor neurons) that each innervate a group of muscle fibres called a motor unit. Activation of a motor unit that leads to muscle contraction is accompanied by electric potentials in the muscle fibres. Surface EMG measures the electric activity in several motor units at the same time.

Functional magnetic resonance imaging (fMRI) is a method of measuring the blood flow in the brain. As active neurons need increased levels of oxygen, the blood flow is dynamically regulated to supply oxygenated haemoglobin to active brain areas. Brain activity thus can be measured as relative difference between levels of haemoglobin before oxygen release (oxyhaemoglobin) and after oxygen release (deoxyhaemoglobin). As oxyhaemoglobin and deoxyhaemoglobin differ characteristically in their magnetic susceptibility, activated brain areas show a different magnetic resonance from less active brain areas. This effect, the BOLD (blood oxygen level dependent) response, is measured in fMRI. Results are achieved by statistical methods applied to the magnetic signals recorded during many repetitions of the action performed by the person in the scanner (e.g., reading sentences or seeing pictures or movie clips).

Magnetoencephalography (MEG) is a method of measuring cortical activity via the magnetic fields produced by electrically active neurons. MEG resembles EEG in many respects, but instead of electrodes, very sensitive measuring devices called SQUIDs (superconducting quantum interference devices) are applied to the scalp. Compared to EEG, MEG has better spatial resolution and very high temporal resolution, but a smaller operating distance, detecting only superficial cortical signals. Because of its specific properties, MEG is often used in addition to other methods such as EEG, fMRI or PET.

Motion capture is a method of recording movements of a (human) body and of translating them into a digital model of the moving body. One well-established method is to fix reflecting markers on the body of the actor and to sample the movement by a set of infra-red cameras simultaneously from different sides. The recorded data are mapped onto a digital three-dimensional body model that can then be made to perform the same movements. Joint angles can be calculated from this model, which gives scientists the opportunity to calculate movement kinematics. This method is used by scientists to analyse the movement of humans and animals, for example in sports, but also by film-makers and computer game designers in order to generate virtual characters that move in a natural way.

Positron emission tomography (PET) is a method of recording three-dimensional pictures of metabolic processes in the human body by use of a radioactive tracer. A short-lived radioactive isotope embedded into a carrier molecule is injected into the bloodstream and transported via the blood circulation to the area of interest, for example the brain. As the tracer decays, it emits positrons, anti-particles of electrons. When a positron meets an electron in the body tissue, both particles are annihilated, and a pair of gamma photons are emitted. These gamma particles are recorded by a luminescent material in the PET scanner. As the blood flow is increased in brain areas with high activity levels, the gamma radiation measured from these areas will also be higher than from less active areas. In a different approach, the tracer can be carried by molecules that bind directly to receptors for specific neurotransmitters in order to monitor the activity of these receptors, for example in neuropsychiatric patients. Even though PET involves the incorporation of a radioactive tracer, it is not dangerous because the dose of radiation involved is very small.

Transcranial magnetic stimulation (TMS) is a non-invasive method of influencing neuronal activity in the brain. Rapidly changing magnetic fields applied with high precision by a figure-eight shaped electric coil induce weak electric currents in the brain tissue. These electric currents interfere with the neuronal activity in the target areas, temporarily "knocking them out", which can lead to measurable effects on task performance, such as increased reaction times. Whereas methods like EEG or fMRI can only help to detect the correlation of neuronal activity in a brain area with a specific task, TMS can give stronger evidence for a *causal* relationship between task performance and brain activity, by showing that suppressing that brain area results in deterioration of task performance.

been used for studying effects related to expertise in dance. Motion capture and EMG have been applied to measure muscle activation and body kinematics during ballet movements in dancers (Lepelley, Thullier, Koral, & Lestienne, 2006; Thullier & Moufti, 2004; Wilson, Lim, & Kwon, 2004). Brain imaging techniques and EEG have been used to study brain activation in dance experts and novices while watching dance (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, Hamilton, & Grafton, 2006; Orgs, Dombrowski, Heil, & Jansen-Osmann, 2008; see also Chapters 8 and 9 by Calvo-Merino and Cross, this volume).

In addition to the described techniques, we can apply behavioural methods from experimental psychology; with these methods we gain access to the level of mental representations (see Chapters 1 and 2 by Schack and Rosenbaum, this volume). In the following, I focus on this approach and on aspects of dance expertise at the cognitive level. To learn about the structural relevance of mental representations of movement, we combine the study of mental representations in long-term memory with the study of biomechanics in our research. We are interested in the cognitive control and biomechanics of complex movements in different types of sports and dance. Our special interest is dedicated to the questions of how such movements are represented at a higher cognitive level, and how this mental representation is linked to movement control and learning.

Movement in memory

In his standard work on classical dance, Nikolai I. Tarassow indicates the dancer's memory as his/her major source of competence that holds the technical and artistic score of the dramatic action (Tarassow, 1977). As Tarassow said, "A well-trained memory assures the mental anticipation of the following dramatic action at any time and leads the dancer safely to success" (p. 64). According to Tarassow, the dancer's memory consists of three parts: auditory, visual, and motor memory. "These different qualities of memory are inextricably linked. They allow the dancer to move in a technically and artistically correct way and to form the movement creatively" (Tarassow, 1977, p. 64, translated from German by the author).

Psychologists distinguish different parts of memory primarily according to the duration for which the content is stored. Anything an individual sees or hears is available for several milliseconds in a sensory storage, like an afterimage or echo (Baddeley, 2002; Baddeley & Hitch, 1974). From this immediate type of memory, relevant information is then transferred to short-term memory, or working memory. Here, information from different modalities, such as images and sounds, is initially integrated. Working memory saves only a few single bits of information called chunks, for up to a minute or a few minutes at the most. The capacity of working memory to hold chunks for longer durations can be extended by training for several minutes and with a larger number of chunks. Furthermore, by using chunking techniques that help to organize information into meaningful units, individuals can contribute to its efficacy. Information whose access might be required for a longer time is transferred to long-term memory, where it can be saved for many years, up to a whole lifetime.

Long-term memory stores different forms of information that are processed in different parts of the brain. In general, two forms of long-term memory are distinguished, declarative and non-declarative memory (Anderson, 1976). Declarative memory contains verbal expressible knowledge about the world. Information in declarative memory is consciously accessible, and can be modulated by thought and explained or expressed in propositions. Events that we remember, like stories we have encountered, are stored in episodic memory, whereas facts that are not linked to specific events any more, such as poems learnt by heart, capital cities, mathematical formulas and definitions, are stored in semantic memory (Tulving, 1972, 2002). Both episodic memory and semantic memory are parts of declarative memory and can be associated with different processing stages. Most facts we have learnt have at some point been linked to episodes, before they become more generalized by frequent repetition and retrieval. The contents of non-declarative, or procedural, memory (Squire, 1992; Squire & Zola, 1996) are not freely accessible to our conscious self and are not immediately available for verbal expression, but we constantly use them in our everyday life nevertheless. Automatized movements and everyday routines such as riding a bicycle, driving a car, swimming, and using tools are stored in non-declarative memory.

In movement learning, declarative and non-declarative memory act in conjunction, building up the individual's motor repertoire (see Chapter 8 by Calvo-Merino, this volume). Let us imagine a dancer who learns a complex movement sequence that is part of a new choreography. The new movements are demonstrated and explained verbally by the choreographer and implemented by the dancer and her colleagues. The situation in the ballet studio in which the dancers learn the movement, the face and voice of the choreographer, the images he gives to illustrate the movement, the comments given by the other dancers, the jokes they make and the questions they ask, are all stored in the dancer's episodic memory. The mere information about how the movement is to be performed, its dynamics and floor pattern, the music that goes with it, and the partners the steps are directed toward, are stored in semantic memory, independent of the anecdotes connected to them. This is the information the dancer would pass on if she had to teach the choreography to a new colleague. Finally, when the dancer practises the movement, all the sensorimotor information she gains is stored in her non-declarative memory. Every time she dances or even mimics the sequence, the movement becomes more and more automatized and thereby more deeply anchored in non-declarative memory and independent of attention, which gives her the freedom to focus on other aspects, such as her partners and her artistic expression. As this is the knowledge she will rely on completely when performing the piece, it is crucial that it contains as much relevant and flawless information as possible.

The close interaction of non-declarative and declarative memory becomes especially obvious when we try to apply corrections to already automatized movements. The first useful step in un-learning an old mistake is often to find a verbal description for what is going wrong and what should be done instead. Language can provide clarity to thoughts and can be used as a tool to manipulate parts of knowledge. This is also true for movement knowledge, where the different qualities of long-term memory are so closely linked (see also Chapters 1 and 5 by Schack and Puttke, this volume). The goal of making implicit movement knowledge explicit by linking it to new, episodic, declarative and, finally, non-declarative content is to improve it and automatize it again in its new corrected form. This process is often more challenging than simply learning a new movement from scratch.

Breaking down complex movements: Building blocks of action

In analysing the knowledge about movements as it is stored in long-term memory, rather than the movements themselves, one must subdivide complex movements into their basic building blocks in a way that is meaningful to the dancers and that resonates with their memory of the stored movement. According to our model, complex movements are stored in long-term memory as a network of sensorimotor information, including perceptual data of different modalities – visual, auditory, kinaesthetic – and semantic content, such as verbal and pictorial markers. The nodes within this network contain parts of the movement in terms of motor action and the associated perceptual information, as well as semantic information, which have been associated during movement learning and movement performance. The node "*plié*", for example, as part of a pirouette, could include bending and stretching the knees while pulling them to the sides, and controlling the position of hips and shoulders and the distribution of body weight, felt as pressure on the soles of the feet. The node "locate eye focus", in comparison, could be linked to looking straight ahead, aligning the head independently of the body, and anchoring gaze direction to a spot in the environment that can easily be detected again directly after turning the head, in order to stabilize the turn, and to minimize the time the face is not facing the audience. The knowledge about a complex movement such as a pirouette can be regarded as a network of such nodes in long-term memory. The better a dancer can perform such a movement, the more orderly the network is organized, and vice versa. The higher the degree of order the network features, the better the knowledge can be accessed, the better the movement can be performed, and the less attention and concentration required for completing the task correctly.

Our aim is to analyse the structure of such networks of movement knowledge in our participants' long-term memory. To accomplish this task, we apply methods from experimental psychology that have been adapted for analysing movement expertise in sport psychology. Before we can analyse the structure of the networks and their degree of order, we have to define the nodes within the networks we want to examine. For each complex movement we want to study, for instance a tennis serve, a somersault, or a pirouette, we have to define a set of concepts that act as such nodes and that we therefore call *basic action concepts* (BACs; see also Chapter 1 by Schack, this volume). According to the *cognitive architecture model of movement* (Schack, 2004a), BACs are functional units for the control of actions at the level of mental representation, linking goals at the level of mental control to perceptual effects of movements. They are conceptualized as representational units in long-term memory that are functionally connected to perceptual events; thus, they have to be differentiated from motor programmes or motor schemata according to Schmidt (see Schmidt, 1975) and from schemata according to Arbib (see Arbib et al., 1987). BACs are activated by representations of starting conditions and deactivated by effect representations, both at the perceptual level. Underlying theories state that actions are represented in functional terms as a combination of action execution and the intended or observed effect, or movement goal (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Knuf, Aschersleben, & Prinz, 2001; Koch, Keller, & Prinz, 2004; Prinz, 1997; Schütz-Bosbach & Prinz 2007a; see also Chapter 8 by Calvo-Merino, this volume). This can also be applied to dance movements, even though the dancer's goal, in most cases, is not instrumental, like operating a light switch, but artistic, like evoking an emotional expression (compare Chapter 2 by Rosenbaum, this volume). BACs can consequently be regarded as cognitive tools for the execution of actions such as complex movement tasks in sports or dance, or other specialist tasks (see Schack, 2004a, 2004b; Schack & Mechsner, 2006). Within these tasks, BACs serve the purpose of reducing the cognitive effort necessary for controlling the action. The same applies to actions performed in everyday life, as they often also require a level of expertise the performer is hardly aware of. Think for example of the cognitive and motor effort a child has to make when learning to tie his shoe laces!

The number of BACs a given movement task can be divided into depends on several factors: on the complexity of the task itself, on the way it has been learnt and trained, and on the level of expertise of the addressee. Therefore, it is hardly possible to define BACs without extensive feedback and cooperation of persons who master the task with different levels of expertise, taking into account their different types of knowledge. Consequently, it is important to take the experience of teachers into account, and also to look at the way the task is actively structured during learning and training, as concepts that emerge during training are likely to remain intact as scaffolding in long-term memory. Additionally, we have to be aware of the nature of the target group of our study, as well as other factors such as their age, linguistic background (as it might concern the acquisition of task skill), and level of expertise. "Expert" BACs might not be experienced by the individual before reaching a sufficient level of performance and, subsequently, might not be integrated into the task-specific memory structure of a beginner; "beginner" BACs, however, might cease to exist for an expert, or branch into several new concepts.

In an experiment, BACs can be represented as pictures or verbal labels that are meaningful to experienced athletes or dancers in order to trigger movement-related memory content. For our studies, a crucial first step was to define BACs that were understandable for novices and still not too trivial or superficial for experts. This was accomplished with the help of experienced ballet teachers, dancers, and amateurs, as well as standard references on classical dance training (Lörinc & Merényi, 1995; Tarassow, 1977; Vaganova, 2002). One reason why we chose classical ballet as a background discipline for our study is that the movements of classical ballet are clearly associated with verbal labels. These labels are commonly used in training, both with beginners and experts. They refer to key points of the movements that can be combined to produce more complex movements in a hierarchical structure and are therefore already closely related to BACs.

Biomechanical movement structures: Functional phases

A basic biomechanical approach to structuring complex movements in sport science is to divide them into their functional phases (Göhner, 1979, 1992; Rieling, Leirich, & Hess, 1967). If we consider a complex movement as the solution to a given movement task, each functional phase then serves the purpose of solving one of its sub-goals, and the interplay between phases leads to the solving of the task in completion. Functional phases are sorted according to their importance for reaching the overall movement goal, which is reached during the main functional phase. Assisting functional phases lead to the completion of sub-goals that support and prepare for reaching the main goal, with primary assisting phases being more important for, and closer to, the overall goal than secondary assistant phases, and so on. As an example, a jump, whether it is a broad jump, a high jump, or a jump shot in basketball, consists of the start-up (primary assisting functional phase), the jump (main functional phase), and the landing (secondary assisting functional phase). Complex movement tasks in dance can be described accordingly, with slight adaptation. For instance, during a jump in classical ballet, the start-up is in many cases replaced by a preparing *plié*. A *pirouette en dehors*, one of the movements we have investigated in our study, can be broken down into four functional phases, with the actual turn taking place during the main functional phase (see Figure 4.3). The turn is initialized during the preparation, predominantly by the *plié*, which is regarded as the main component of the primary assisting phase. The primary function of this phase is to build up

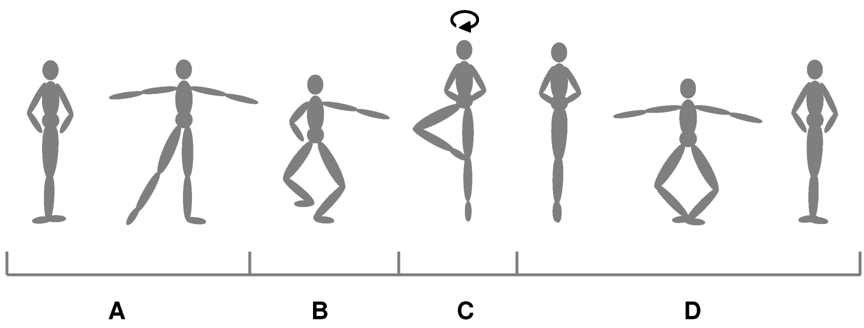

Figure 4.3 Cartoon of the *pirouette en dehors*. Functional phases: A – second order assisting functional phase: body alignment and pose; B – first order assisting functional phase: build-up of elastic forces for the turn; C – main functional phase: turn; D – final assisting functional phase: catching the turn and pose. The following BACs have been used in the study: phase A – (1) stand, right foot in front; (2) open arms for preparation; (3) right foot slides to side; phase B – (4) move right arm to front; (5) move right foot back; (6) bend knees; (7) locate eye focus; phase C – (8) stabilize body axis; (9) close arms; (10) push left leg into ground; (11) right foot up to left knee; (12) turn head; phase D – (13) relocate eye focus; (14) close right foot behind left; (15) open arms after turn; (16) bend knees, stretch (modified from Bläsing, Tenenbaum, & Schack, 2009b).

elastic forces for the turn. During the first part of this preparation, the secondary assisting phase, the body is aligned, and the attention of both the dancer and the audience is focused on the following turn. During the final assisting phase, the turn is halted and the body is shaped into a terminal pose.

In our study, we used biomechanical movement structures based on functional phases as reference for mental representation structures in our participants' long-term memory. Our hypothesis was that representational structures in the long-term memory of expert dancers would strongly involve their implicit knowledge, reflecting frequent correct and automatized performance of movement, and would therefore intrinsically correspond to the functional phases of the given movement. Similarly, we also expected the representation structure of less experienced dancers to be less consistent with the functional phases, because of the lack of reliable and "correct" movement-related information stored in their non-declarative memory, and the lower degree of order in their corresponding knowledge network.

A study of cognitive structures in dance

In the mentioned study, we have analysed how complex dance movements are stored in dancers' long-term memory, and in what way professional and amateur dancers differ from one another in this respect (Bläsing, Tenenbaum, & Schack, 2009b). Participants were professional dancers from the Ballett Dortmund, Tanztheater Bielefeld, and aalto ballett theater Essen, amateur dancers from different ballet schools and a control group of sport students who had never been trained in classical, modern, or jazz dance or related disciplines. Amateurs varied to a great extent regarding their training experience, quantitatively as well as qualitatively, and were therefore divided into two groups: advanced amateurs who had trained in classical ballet for more than 8 and up to 20 years and beginners who had trained for less than 5 years.

Whereas amateur and novice participants were mostly tested at our memory lab, the data acquisition with expert participants took place in theatres, in the canteen, or in the ballet master's cloakroom during breaks between training sessions and rehearsals. Initially, most dancers regarded the experimental task with a mixture of curiosity, interest and suspicion. Several of them had even worked on scientific questions related to dance themselves, or had read about studies on movement control and learning. Most of the dancers, however, were new to our improvised lab situation. Questions such as "Will I be judged personally here?" and "What if I fail in this test?" were asked, and participants also wondered "What can I gain from this?" and "Will this improve my dancing?" Several dancers were pleased when they saw that we regarded them as the experts we wanted to learn from, and almost all of them were rather puzzled when we asked them only to press keys on the computer, and not to dance or move at all, unless they found it helpful for the experimental task. Even though the subjects of the tasks were movements that were very familiar to the dancers and belonged to their daily routine, the mode of thinking about these movements during the experiment seemed quite peculiar for most of them. Dancing a pirouette is, in fact, very different from sorting its parts in verbal description on a computer screen, isn't it?

What movements to study?

In pilot studies, different movements with several sets of BACs were tested. Ultimately, we agreed on the *petit pas assemblé* through the second position and the *pirouette en dehors* from the fourth position. Both movements are sufficiently complex, and coordination is important in both of them to facilitate the goal of the main functional phase, a jump in the *pas assemblé*, and a turn in the *pirouette en dehors*. Both are considered part of the basic movement vocabulary of classical dance, and both are part of the daily routine of professional dancers and common to the training sessions of amateur ballet dancers. Therefore, we could assume that professional and amateur dancers alike held visual expertise along with motor expertise of both movements, depending on the amount and level of their dance training.

There are, however, crucial differences in biomechanical structure between the two movements that make them interesting to compare. The pirouette is a rotational movement that requires highly defined coordination and constant adjustment of the body axis in order to be performed with adequate stability and perfection. It includes a preparation phase, and can also be clearly separated into four functional phases, as has been demonstrated (see Figure 4.3). The *pas assemblé* is a transitional movement. This small jump consists of three functional phases: (1) the *plié* by which the elastic take-off energy is built up, (2) the jump, and (3) the landing (see Figure 4.4). The *pas assemblé* is

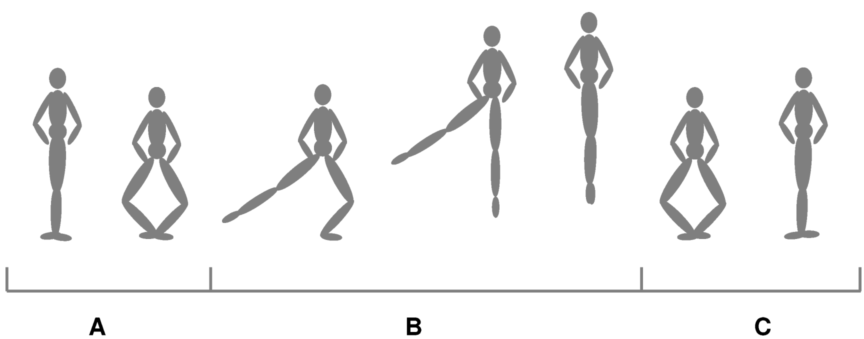

Figure 4.4 Cartoon of the *pas assemblé*. Functional phases: A – primary assisting functional phase: build-up of elastic forces for the jump; B – main functional phase: jump; C – final assisting functional phase: landing after the jump. The following BACs have been used in the study: phase A – (1) stand, left foot in front; (2) bend knees; phase B – (3) right foot slides to side; (4) lift right leg; (5) jump from left leg; (6) stretch left leg in air; (7) join legs; phase C – (8) land on both feet; (9) bend knees, stretch (modified from Bläsing, Tenenbaum, & Schack, 2009b).

performed at a much quicker pace than the *pirouette en dehors*, most often as part of a sequence of small steps and jumps. If regarded as part of such a sequence, it bears resemblance to circular movements such as swimming strokes or ski turns, with the third and first functional phase of consecutive jumps, both assisting phases, melting into one another. Comments given by the dancers also supported our impression that the pirouette is more likely to become a subject of reflection, as one of the dancers remarked: "The pirouette is something I think about, but the *assemblé* is something I just do!"

Pirouettes on the computer screen

The experimental task we asked our participants to do was to judge the functional closeness between pairs of BACs that appeared listed in random order on the computer screen (the method is described in detail in Chapter 1 by Schack, this volume). If the list featured, for example, the BACs "*demi-plié* in preparation" marked red, and "turn head" marked yellow, the resulting question was: "With respect to the *pirouette en dehors*, do you consider turning the head functionally close to or not close to the *demi-plié* in the preparation?" Initially, participants found this task rather confusing, as the lists of BACs were constantly shuffled and presented repeatedly. As participants carried on with the task, however, they discovered a way to shed light onto the apparent thicket of abstract movement terms by recalling implicit movement knowledge from their long-term memory. To judge the functional proximity of the concepts in question, they had to imagine dancing (or even physically dance or mimic) a pirouette or an *assemblé* and to use the kinaesthetic perceptions associated with this movement for their decision. To make the experimental situation equally acceptable for experienced dancers and non-dancers, we allowed all participants to try out the movements both before and during the experiment. Most participants made use of the option to get up and attempt the movement or to mimic the movement while sitting. This was done to activate their knowledge by trying out "what the movement felt like". Novices tried the new movement several times before the experiment, until they felt that they understood how it worked, and many of them also interrupted the experiment to get up and try again. Most experts and amateurs mimicked the movement repeatedly during the experiment, without getting up, to assist its retrieval from long-term memory.

The method we applied (*structural dimensional analysis – motoric*; see Chapter 1 by Schack, this volume) has been derived from experimental psychology and has been validated in the analyses of mental representations of complex sports movements (e.g., Schack, 2004a; Schack & Mechsner, 2006). From the decisions made by the participant, a distance matrix is calculated and scaled, and a hierarchic cluster analysis is carried out to define which BACs belong together in the mental task representation of the participant. For more information about the theoretical background, see Lander (1991) and Schack (2001). Our rationale for applying this method lay in its potential to provide access to the level of mental representation that is based on declarative as well as non-declarative knowledge in long-term memory. Asking participants directly about their representation of a special ballet movement would predominantly address their explicit knowledge about the task, which, in the case of a well-trained ballet dancer, might be rich. It would, however, not provide access to the long-term memory content that structures and controls the actual execution of the movement. After all, not everyone who is capable of describing a *pirouette en dehors*, or of judging its quality when someone else is performing it, is also able to perform the movement correctly themselves. Additionally, not every dancer who can perform a pirouette perfectly can also give an expert description of it.

The interest dancers took in our work, especially after they had finished the experiment and had thereby already gained an impression of what it was about, exceeded our expectations. In many cases it led to vivid and fruitful discussions about body and mind, movement and thought, their work and our work, so that we hardly found enough time to answer each of the participants' questions and to have our own questions answered. For many of the dancers, the experimental procedure had already generated its own light bulb moment, and participants considered this explicit way of thinking about movements as rather uncommon, but beneficial for their work. Several expressed that they had never thought about their dance movements in such detail before. "Now I should finally understand what I do every day" one dancer said, "I wonder if that will show during my next training!"

Supporting and surprising results

Our guiding hypothesis was that the cognitive movement structures of experts would correspond to the functional phases, whereas the cognitive structures of novices would not. The results, displayed in Figure 4.5, confirmed this general hypothesis, but also offered a few surprises. As expected, the professional dancers' representational structure of the pirouette corresponded to the functional phases, but so too did the representational structure of the group of advanced amateurs (Bläsing et al., 2009b). The main difference between these two groups concerned the BAC "stabilize body axis". This concept was included in the primary assisting phase by the advanced amateurs, whereas it was singled out by the professional dancers. When we asked

Figure 4.5 Results of our study of the *pirouette en dehors*, displayed as dendrograms: A – professional dancers; B – advanced amateurs; C – beginners; D – novices. The numbers on the bottom line mark the BACs, see Figure 4.3. The numbers on the right relate to the horizontal bars in the dendrogram, they indicate the Euclidean distances between the BACs: the lower the horizontal bar, the smaller is the distance between the corresponding BACs in long-term memory. The dashed horizontal line indicates the critical alpha value: only structural links between BACs with distances below this value are considered relevant (modified from Bläsing, Tenenbaum, & Schack, 2009b).

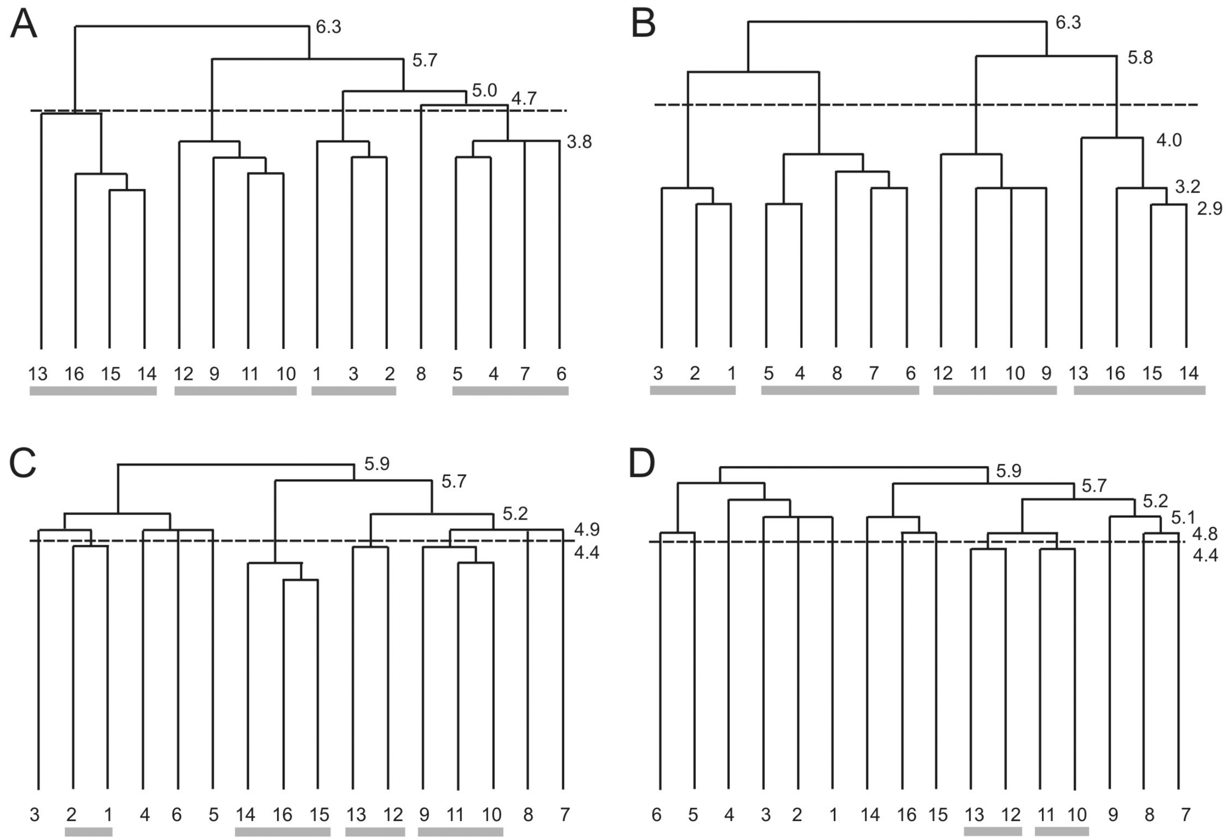
A
6.3
5.7
5.0
4.7
3.8
13 16 15 14 12 9 11 10 1 3 2 8 5 4 7 6
B
6.3
5.8
4.0
3.2
2.9
3 2 1 5 4 8 7 6 12 11 10 9 13 16 15 14
C
5.9
5.7
5.2
4.9
4.4
3 2 1 4 6 5 14 16 15 13 12 9 11 10 8 7
D
5.9
5.7
5.2
5.1
4.8
4.4
6 5 4 3 2 1 14 16 15 13 12 11 10 9 8 7

Figure 4.5

participants about this result, the dancers agreed that this was not an action that was part of the pirouette, but was a prerequisite to all movements in classical dance, an actual state they were in “all the time, anyway”. Amateurs, by contrast, reported that they focused their attention on the body axis right before initiating the turn. The results of the beginners showed far less consistency with the functional phases. Specifically, the BACs of the turn were grouped in a less functional way, and most of the BACs of the preparation were singles. As expected, the results of the group of non-dancers showed hardly any structure at all.

The *pas assemblé* also offered some surprises. In fact, all groups, even the novices, had structured the movement in a more or less functional way. The results of the groups of amateurs and novices, however, all featured the same break after sliding out the non-supporting leg to the side before the jump, suggesting that this part of the movement is not efficiently used for increasing the bounce but, instead, might be regarded as an “extra effort” before jumping (Bläsing et al., 2009b). The result of the expert group was unique in that separating the movement after the *demi-plié* and including the action of the non-supporting leg with the jump corresponded to the functional phases. This structure allows for the non-supporting leg to add to the jumping impulse, resulting in a greater bounce.

More studies on cognitive dance expertise

The results of the studies described above as well as numerous discussions with dancers during data acquisition have led us to new and related questions that build on the work we have presented here. The close resemblance between the results of the professional dancers and the advanced amateurs in our pirouette study is surprising, and prompts investigation of the differences between various levels of expertise. Was our set of BACs too coarsely meshed to represent the mental representation of a higher expertise level and to specify differences between professional dancers and advanced amateurs? To find out, we defined a new, more refined set of BACs for a subsequent study. The new set consisted of only 12 BACs, specifically describing the main functional phase, the actual turn, without the preparation and final pose. We also measured the exact timing of the experimental procedure (i.e., the time each participant needed for each single decision). During the first study, we did not pay attention to this aspect of measurement; however, even though we had instructed the participants that “time did not matter”, and despite the vast variance in processing time, we surmised that this parameter might carry some relevant information about the nature of expertise. Furthermore, taking into account different relations of declarative and non-declarative knowledge, we included a group of ballet teachers in our study. This was done in an effort to compare them to the group of dancers who were not also teaching and were therefore less used to explaining movements. During data collection we encountered very lively discussions between the participants, which showed us that, in this case, expert knowledge was challenged rather strongly.

In further experimentation, we investigated the role of mental representations of spatial directions in dance expertise. Dancers often use spatial directions in an egocentric frame of reference, relative to their own body, as mental cues for supporting movement performance and for shaping movement quality. The aim of this practice is to support the stability and quality of movements as well as their artistic expression, for example by associating opposing directions giving maximal stretch to the dancer's body. We used the *pirouette en dehors* with the first set of BACs and applied the same method as in the first study. This time, however, participants did not have to associate the BACs to one another, but were asked to relate them to spatial directions, such as front, back, left, right, up, down, close, and far. This resulted in questions such as: "What directions relative to my body do I associate to the *plié* before the turn?" It turned out that only the group of professional dancers produced a functional movement structure on the basis of movement-related directions, suggesting that the mental representation of body-centred spatial directions provides a valuable tool specifically for, and probably exclusively to, dance experts (Bläsing & Schack, 2008). In addition to the studies of mental representations of movements in classical dance, we are also interested in the question of how cognitive structures relate to physical measures of movement performance. Therefore, studies of the kinematics of ballet movements are currently being carried out in our lab (Figure 4.6).

Another aspect of dance expertise we are interested in is linked to the visual perception of movements. Several studies showed differences in brain activation of dance experts and novices while watching dance (Calvo-Merino et al., 2005, 2006; Cross et al., 2006; Chapters 8 and 9 by Calvo-Merino and Cross, this volume). Results of these studies support the idea that we perceive actions we have previously performed ourselves in a different way from actions we have never performed, even if we might have watched them (Schütz-Bosbach & Prinz, 2007b). It has been demonstrated in different sport disciplines that experts can pick up more information from short cut-outs of visually presented movements than can novices. An experienced cricket player who watches only a few milliseconds of a batting movement can still extract sufficient cues to determine where the ball will be headed (Müller & Abernethy, 2006; Müller, Abernethy, & Farrow, 2006). This perceptual aspect of movement expertise has been studied using a temporal occlusion paradigm in which the participants are shown short video clips that reveal progressively increasing information about the same movement. We applied this paradigm to basic movements from classical ballet, investigating the ability of dance students to determine the type of movement and, given that it was a turn, the side of the supporting leg and turning direction (Bläsing, Homeier, Sossinka, & Schack, 2009a). In this case, we were not only interested in the ballet students' increasing visual and motor expertise, but also in lateralization effects that might occur with respect to true and false answers. Everyone has

Figure 4.6 Dancer in the biomechanics lab. This dancer who is participating in a biomechanical study is equipped with retro-reflective markers on defined parts of her body. As she moves, 12 infra-red cameras (two of which are visible in the upper part of the picture) track the movement of these markers. The data collected by all cameras is sent to and integrated by a computer that calculates from this data a 3D model of the dancer's body (displayed on the monitor in the background) in real time. Dancer: Tanja Rastvorov. Photographer: Stefan Krüger, Research Institute for Cognition and Robotics (CoR-Lab), Bielefeld University.

an inherently favoured supporting leg and turning direction, but dancers are trained for symmetry in order to overcome this natural constraint.

At the beginning of this chapter, I described how a complex movement can be broken down into segments for different purposes. A dance trainer who teaches a complex movement sequence is faced with the same problem, breaking down the movement sequence into meaningful parts. This might be necessary to facilitate students' learning process; however, it might also result in unwanted segmentation that interferes with flow of the movement later on. In one of our studies, we asked how dancers and non-dancers would segment different types of movements displayed in video clips, what cues they would use, and how imitating or learning the movements would influence their choice. Other authors have studied event segmentation using everyday activities such as making a bed or washing the dishes (Speer, Swallow, & Zacks, 2003; Zacks, Tversky, & Iyer, 2001). These actions differ from dance movements mainly in two different aspects: they include the interaction with objects, and their goals are defined changes in the states of these objects (after the action, the bed is made, and the dishes are clean). As previously mentioned, dance movements in most cases do not have such object-directed effects, but their goal lies in the artistic expression of the movement itself. Using dance movements as stimuli in a segmentation task (see also deLahunta & Barnard, 2006), we want to find out how this difference in the movement objective affects the way observers structure it and how this is related to their expertise for dance movements. This study, like most others described here, is still work in progress.

Conclusion

In this chapter, I have strived to illustrate how scientists regard movements and motor behaviour they wish to study, and how they process them in order to gain access to different levels of motor control. I have then focused on the level of mental representation in long-term memory and its relevance for dance. To explicate the approach taken here, I have introduced basic action concepts as functional units for the study of mental representations of movements, and described how they relate to biomechanically defined functional phases. At the core of this chapter, I have presented a study in which dancers, dance amateurs, and non-dancers were compared to each other on the level of their mental representation of the *pirouette en dehors* and the *pas assemblé*. Finally, I have raised several questions that my colleagues and I are interested in and currently working on, in order to indicate where the journey is going. The aim of my story was to demonstrate why studying dance is such a fascinating issue for those interested in cognitive aspects of movement, and how the cognitive effort put into learning and optimizing movement can serve to elaborate dance.

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Part II

The dance perspective

5 "Learning to dance means learning to think!"

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It all began 30 years ago, in 1978, with an accident. I had a student, a 16-year-old boy, artistically one of the most talented youngsters in the school, although the results of his physical assessment at the entrance audition had put him in the lowest class. During a break between classes, this boy and some of the others were playing about in the studio, enjoying the height of the jumps that, as dancers, they were able to achieve with the help of a spring-board, never thinking that after a soaring flight through the air, a safe landing is extremely important. He landed wrongly, breaking his landing leg diagonally right across the shin, with extreme lateral dislocation of the fractured lower leg. There followed months of medical treatments and procedures, then weeks in plaster and finally the verdict of the doctors, that that was the end of the dream of becoming a professional dancer.

At the time of the accident I was at the beginning of my teaching career, and had been away for several weeks. Faced with a problem of this type, I found myself at the limit of what I had been taught, even though I was every bit as motivated as these young ballet students. I had just returned home, bursting with knowledge from my studies at the Theatre Academy in Moscow. I remember visiting him in hospital, and asking him what he thought he would do in the future, to which I received the tearful answer: "The only thing I can do and want to do in my life is to dance! Nothing more nor less. To dance!" My reply was as carefree and inexperienced as his jump from the springboard had been. I said to him: "Then you will!"

During the next 4 to 5 years he had to undergo two further operations; however at the end of this period he had also taken gold medals in two of the most significant international ballet competitions, Helsinki (1984) and Jackson, Mississippi (1986). In sporting terms, he would be described as a world champion twice over. He became an internationally celebrated star, one of the very few German dancers able to point to a worldwide career. He continued to dance until his 44th year, a very advanced age for a male dancer. How was this possible for a dancer, obviously hampered over long periods by seriously physical limitation, to the point where he really could have been expected to wind up in the handicapped category, rather than in the Olympics of dance?

It had already occurred to me during normal classes at the beginning of my teaching activity that a high percentage of dancers' mistakes are not because of a lack of ability or preparedness, but rather because of a completely erroneous notion of the character and sequence of a movement they are required to learn. Apart from numerous other factors, for example, that the teacher is demonstrating the movement with a 30-, 40- or 50-year-old body, after which the student attempts to repeat and reproduce this with the body of a 10-, 12-, 14- or 16-year-old. No attention is paid to the different starting points in terms of the physical, intellectual, characteristic and emotional development of this child or teenager. The child's perception and understanding of a movement proceeds in ways completely different from those imagined and intended by the teacher. *A child, in other words, is not a miniature version of an adult*.

I have always been fascinated to watch divers jump from the 10 metre board, carrying out the most complicated twists and turns without ever having had the opportunity to learn these actions under real conditions because of the extremely high risk of injury. The question arises: How is this possible? I discovered that the athletes undergo an intensive regime of mental training in advance, working over and over again with film sequences until the movement is perfect in their heads, both in point of technique and as regards the given time limit. Thus it was that I began to work with the injured dancer on cogitation (analysis, or mental control) and the concrete pictorial objectification (mental image, or mental representation) of a movement or a movement sequence in an incredibly time-consuming process of tackling the movement mentally, until a specific quality had been achieved. Only at this point did I allow him to reproduce and execute the movement (sensorimotor representation). (The terms *mental control, mental representation* and *sensorimotor representation* can be referred to as the *cognitive architecture of movement* model, see Chapter 1 by Schack, this volume.) As a rule, the dancer was made to start the process of working on a dance sequence by lying on the floor, to eliminate the sensation of body weight (I subsequently discovered this to be the decisive moment from the point of view of the neurologist). He had to close his eyes for a given period of time, then give me the verbal feedback on his picture of the movement until the required quality had been achieved. We then worked on the movement in a standing position. With verbal corrections from me, and the corresponding verbal feedback from the dancer, the sequence acquired yet more quality. For anyone familiar with the daily working routine in a ballet studio, this was an apparently unnatural procedure. The speed of the movement sequence was then increased, until it could be executed within the time limits required by the music, after which I allowed the dancer to mark the sequence with maximum economy of movement, at the same time picking up and correcting any potential mistakes of impulse or the preparation of steps. There followed a short warm-up phase, then finally I allowed the dancer to execute the movement under real conditions; that is, with music, dealing with approximate real spatial requirements and the corresponding investment of strength and attack.

The quality of movement execution was convincing, in many respects improved. The process of learning the most complicated movement sequences, normally requiring weeks, months or sometimes even longer, had been carried by this technique of "doing nothing" (which is to say, not dancing) to a whole new level. This *ideokinetic training* bore no relationship to the usual excessive physical training of ballet dancers. One could undertake conditioning, relative to the physical shape of the dancer, in a relaxed and well-balanced manner, as the dancer always knew precisely what he had to do. This was my first confrontation with the interrelation between dance and thought, the mental representation of a movement sequence in the brain, and its physical reproduction. It seemed to me essential in this process that the dancer should not start the movement learning process from the standpoint of his own coenaesthesis, but should instead work consciously to influence the movement through step-by-step mental correction, gradually developing the quality. The actual development of the physical execution of the step starts at a much higher level, which is to say that the concept of the movement is already clear in the head, before the dancer has even taken a step. It then needs to be conditioned and repeated often enough for it to become automatic (see also section on mental training in Chapter 1 by Schack, this volume). The principle of "learning by doing" in dance has acquired an entirely new meaning. If I prepare the movement mentally in advance, the body finds it much easier to respond with the appropriate technical and aesthetic form, or to satisfy the relevant artistic and interpretive demands. If we eliminate this process, the body is faced with an exhausting, and normally (depending on talent) a very long process of searching and feeling. Not infrequently, this path might lead to a dead end.

Dance is in the first place an artistic, rather than a sporting activity. This is, however, dependent on optimal mastery of the technical challenge, the artistic and interpretive requirements, and the demands made on the body as an instrument of artistic expression. The less the dancer is subject to physical and technical difficulties or insufficiencies, the greater is his artistic freedom in the performance and interpretation of dance. The dancer can only work freely with his body in artistic performance when he no longer fears the danger (particularly in some of the unbelievably difficult contemporary choreographies) of landing any moment on his nose or on his behind. The unbelievable quality of his long-term memory capacity for movement sequences (see also Chapter 4 by Bläsing, this volume) becomes clear when we realise what actually happens onstage under performance conditions. Not only must his body function at optimum efficiency, he also has to manage the tempo changes emanating from a live orchestra, which can throw his carefully memorised program completely out of kilter. The careful work of many weeks, precisely defining movement in space and time, can be rendered meaningless in a fraction of a second. Contact with the partner or with other dancers brings further unpredictability to the performance, as they, too, react in their own way and without warning to unrehearsed occurrences on stage during the dance. Often enough, the presence of hundreds of spectators and the awareness of their expectations can force the dancers into a condition of psychological stress that can only be described as borderline. All of this happens under the strict condition that a creative or interpretive event of absolute emotional conviction has to be projected “over the footlights”. Any ostensibly technical demonstration or visible correction would destroy the artistic expression. This places emotional, mental and physical loads of the highest intensity on the person, loads that as a rule are found only at the limits within which we function.

There is a need for independent scientific research into the psychology and physiology of the dancer, because education for professional classical and modern dancers (especially for dance in the theatre) takes place during the most complicated phase of human life. It starts in childhood. It continues into puberty, the most difficult phase of human physical and mental and emotional development. The body, simultaneously at the mercy of all these influences, is being instrumentalised. It ends with the first stages of adulthood, usually at the age of 18. *Self-discovery and a whole new set of rules at the same moment!* The body is trained to become an instrument, which in the interpretation of a role can also be seen as an object. A very complicated interrelationship arises between the person of the artist (subject) and the body as the instrument of artistic expression (object). This very particular subject–object relationship creates a particular interface between dance and cognitive science that would require an interdisciplinary collaboration of psychology, neuroscience, biology and philosophy, among other disciplines, to be understood. Anyone who recalls the errors and confusions of their own puberty will certainly understand how hard it must be in this profession to satisfy the simultaneous demands of normal academic school, training for a career, and one’s own sudden coming of age, and to bring it all into proportion. There is no other profession, or at any rate none that I can think of after long consideration, that demands such a complex interaction of body and mind at such a high level. A profession that, however, compared with other artistic professions or indeed professions in general, receives so little public recognition.

Let us look briefly at the school of classical dance, in which somehow or other the finished product must be produced. It has passed through many stages in the course of its history. The significant beginning took place in Russia in the course of the last century in St Petersburg and later in Leningrad, when the legendary Agrippina Vaganova filtered out from among the prodigious quantity of existing steps, Italian, French and Russian styles and techniques, the decisive material for the training of professional dancers and combined it into a system. Her revolutionary achievement lay in the reduction and simplification of the overwhelming mass of material to its essentials. This system is still working today, and can form the basis for dance training in our time. The resulting canon of movements rests basically on an understanding of the body as an instrument of artistic expression, which has freed itself from certain of the norms and restrictions of normal human movement ranges. In other words, normally we move forwards; to move backwards can sometimes leave us looking at least clumsy, if not indeed handicapped. Our anatomy only allows free movement, and a significantly larger volume of movement in a forward direction, while in retrograde movement the hip joint restricts movement in many respects. The British cyberneticist Kevin Warwick described the problem almost wistfully, when he talked about the human body being extremely limited in its capabilities, and said he would really like to be able to rebuild himself.

In dance the physical structure of the body and sometimes even the normal rules of physics appear not infrequently to have been dissolved. The body is equipped by means of the particular training of classical dance, and the spectrum of its movement, and thereby also its expressive possibilities are significantly expanded. Particularly in contemporary choreography, the body is frequently expected to display a facility for self-transformation that carries every organic sequence of movement to absurd extremes. Part of the basis for this results from classical dance training, in the course of which, for example, the body is trained to execute a specific movement sequence either forwards or backwards, with one leg and then with the other, without the slightest alteration to the sequence structure. One example of this would be the element *battement tendu*, which starts forwards or backwards, with the right and the left leg. Four variations, then, on one and the same tiny piece of choreography. Parity is thus inculcated for both legs, as is the ability to execute steps in different spatial directions, an indispensable prerequisite for the dance of any choreographer. When one considers the difficulty experienced by non-dancers simply in walking backwards, one can measure what an unbelievable challenge is being posed here to the motor control system – a challenge for cognitive science and the understanding of movement in dance. Or in the words of a great musician and composer, Friedrich Liszt, who observed with eloquent simplicity, that one does not play the piano with two entities (by which he meant two hands, the right and the left) but with one two-handed entity or with 10 equally important fingers.

For every human being, for example the predisposition to right or left preference is a matter of natural fact. The execution of a dance movement becomes in this context a matter of course, regulated by processes of self-activation. The motor system functions as a cybernetic system. The problem when learning a dance technique, especially the practically objective classical technique, is that in general these regulations are negated or at least insufficiently observed. Individual movement experiences, stored in the *movement memory bank*, and natural reflexes play a subsidiary role. Their integration into the methodological process means an a priori acceptance on the part of the individual, as opposed to their negation in favour of an alien system of movement. For artistic practice in general and for artistic education and training in particular, this creates a paradigm change. There has been no lack of argument in the past over this problem, the relationship between the individual and the technique of dance, and this applies even to the most different modern dance styles and techniques, each giving priority to either one side or the other. Dance research has concentrated principally on the perspective of anthroposophic science, sociocultural context, ethnological or artistic and historic roots. Observations based on natural science have so far been relatively marginal, and where they exist at all, have been neither correspondingly recognised nor further developed, in the way that, for example, Martha Graham, Agrippina Vaganova or Rudolf Laban (see Box 5.1) most appropriately did as they developed their systems and analyses during the 20th century. The training or re-training of the movement apparatus and its psychomotor control almost exclusively by way of the physical sensations of the student produces in my experience a real labour of Sisyphus, many things are left to chance, and failure is every bit as likely as success. This has been, however, in principle, the only method of teaching ballet for several centuries, on the basis of "learning by doing".

To work, to repeat, to sweat, again and again – this has brought classical dance into disrepute as an inartistic, exclusively technically oriented school of

***Box 5.1* Important names in the world of dance**

Martha Graham (1894–1991): Dancer, choreographer, teacher; greatest exponent of the American modern dance and founder of the Graham Technique, which influenced the development of modern dance worldwide.

Rudolf von Laban (1879–1958): Hungarian dancer, choreographer and explorer of human movements; he worked in Germany and created the modern European "Ausdruckstanz" and one of the most logical systems for notating movements, the "Laban notation", which is based on the body and its possibilities for movements.

Agrippina Vaganova (1879–1951): "one of the greatest masters of the ballet of all time" (*The Dance Encyclopedia*, New York, 1967); Russian ballerina, choreographer, world famous teacher for classical ballet, and founder of the Soviet system of ballet education. The Vaganova System reformed and influenced ballet schools all over the world and is still today the base for the education of professional dancers.

Heinrich von Kleist (1777–1811): German philosopher and writer, deeply influenced by the Enlightenment (Immanuel Kant, Jean-Jaques Rousseau); his essay "On the Marionette Theatre" ("Über das Marionettentheater"), which appeared first in the *Berliner Abendblätter* in 1810, is still today one of the most important publications about the relationship between thinking and moving.

movement. Modern dance, on the other hand, is based on a natural, organic feeling for movement. Individual movement patterns become the starting point for the training of the body and for artistic expression, and are seen as the source of artistic renewal for dance in the 20th century. So the techniques of classical ballet and modern dance remain, as ever, in opposition, and their shared elements remain marginalised both in training techniques and in education. The revolutionary integration of dance steps into a unified system by the brilliant Agrippina Vaganova during the first half of the 20th century is even today not properly studied for its inner content and context, but instead is taught and learnt as an aesthetic and technical norm or standard. The canonising of classical dance becomes standardisation. The natural and organic roots from which classical dance developed over 200 years recede into the background. They are unrecognisable, unimaginable, irreproducible in the technical structure of the movement sequences, and in this sense undetectable. The contradiction between classical and modern dance seems even today to remain obstinately real, although the will and the readiness of many to eliminate this antagonism has long been there. Creating awareness of the function of our movement apparatus, the mental analysis and imagery of single movements or sequences as described above, renders the holistic, equal and organic qualities of an artificial dance movement comprehensible. I can discern here enormous possibilities for the amelioration of the learning process, because the traditional methods of imitation and endless repetition can also easily inculcate false structures in the movement memory (see Chapters 1 and 4 by Schack and Bläsing, this volume). To learn completely new sequences and experiences of movement, the student is able by means of ideokinetic training to "override" his coenaesthesis. My basic assumption must be that my coenaesthesis mirrors that of a normal untrained body, capable of a limited range of movement and unilateral – considerations that the dancer (or the pianist) must indubitably overcome in order to work professionally.

In the famous essay "On the Marionette Theatre" by Heinrich von Kleist (1810/1987; see Box 5.1), we find the following interesting proposition relative to the problem of mental imagery. The author addresses the central question of whether human action is governed by feeling or by rationality. The narrator recounts his conversation with a dancer, much admired for his grace, whom he has several times seen visiting the Marionette Theatre. The man whom he has accosted explains how he admires the natural graces of the puppets, and how much he himself is able to learn from them to what extent a natural harmony of movement can exist, independent of conscious thought (see also Chapter 3 by Cruse & Schilling, this volume). Beside the jointed puppets of the Marionette Theatre, the narrator mentions the example of a graceful young boy who becomes aware of his grace and perfect harmony of movement, in which he resembles the famous statue of the *Boy With A Thorn In His Foot*. Realising that he is being observed, the boy tries under conscious control to repeat the movement in its original beauty, and fails in the attempt.

During the conversation, the thesis arises that either completely unselfconscious movement (as in the string puppets of the Marionette Theatre) or at the opposite extreme, complete intellectual control of every action (as in the case of a perfect actor) both produce the desired "natural" grace. Complete grace and "naturalness" are thus the property of someone who either functions in a childlike state of complete naiveté and unselfconsciousness or who regulates his behaviour through total rational control, "so that, when cognition is processed ad infinitum, grace is again present; so that it simultaneously is most clearly discernible in one and the same human form possessing either none at all, or else infinite consciousness, which is to say either in the string puppet or in God" (von Kleist, 1810/1987, p. 345).

With reference to the dance profession: the expression of the highest professionalism in dance is precisely complete grace and naturalness of a very high order, achieved by a completely intellectual control and mastery of the mechanical skills. The ability of a pianist to employ left and right hands as a holistic movement system is undoubtedly a prerequisite for good piano playing. It is, however, many times surpassed by the psychomotor performance of a dancer, who must use the entire body as a whole, of which the individual components must function both completely independently and at the same time in the closest interrelation with each other. In addition to the equivalence of left and right, in dance there is also the equivalence of arm and leg, of forwards and backwards. There is no question that some talented individuals certainly exist who possess this capability and who even, despite bad teachers or ballet masters, achieve better than average artistic performance levels. These talented individuals, however, are seldom seen. These parities, which manifest themselves in a highly developed canon of movement, are taught in the training of classical dance. With the help of a system of body coordination and various arm or leg positions, the steps of classical dance are strictly regulated. All movement must run through these positions. These are so fundamental that they are also used in other styles of modern dance. They depend entirely on the value system, the parities and the equivalences previously alluded to, and they produce on the basis of their aesthetic significance the spatial and biomechanical integration inherent in the context.

The *cognitive architecture of dance movement*, and in particular of the transitional movements, must be learnt, understood and absorbed by the dancer. He or she must *know, prior to the beginning of the movement, why the movement is executed*, otherwise it may easily be meaningless. This clearly demonstrates the interrelation between cognition and biomechanics. Analysis of hierarchically structured movement sequences (in classical dance, the clear separation between principal elements and assisting or preparatory movements; examples are given in Chapter 4 by Bläsing, this volume), mental comprehension of the so-called node points, and their physical reproduction exercise a defining influence on the memory structure of the movement (Chapters 1 and 4 by Schack and Bläsing, this volume, elaborate on these topics from a perspective of cognitive movement science). Their verbalisation, very unaccustomed and therefore deeply disliked by students and dancers, creates the opportunity even prior to physical reproduction, to monitor and improve quality of movement. The canon of classical dance consists of about 450 separate movements and elements of movement, which are taught in every academic ballet school in the world in the course of an education lasting around 8 years. This is intended with the help of the coordination system, the positions of the arms and legs and the canon of movement, to develop the body into an artistic instrument. Every movement is first demonstrated separately by the teacher, then repeated hundreds or even thousands of times by the student, until it has established itself in the memory and can be physically executed. The body will be, so to speak, constructed as an artistic instrument from these separate elements, as the individual building-blocks may then be combined into complicated movement according to form or need. Even today, prevalent notions of teaching unfortunately look as mechanical as this process sounds. The separate parts of the body are put together like some sort of human jigsaw puzzle, on the basis that, the better the individual elements are trained, the better will be the dancing at the end of the process. This is a fatal confusion.

For the whole is not equal to the sum of its parts. Even worse, however, is the fact that a mechanistic model has established itself in the mindset and understanding of classical dance that deprives all classical interpretation of its vital nourishment. One could also say that the dance has lost its soul! Or, to quote Heinrich von Kleist again (1810/1987, p. 345): "It must fall back into a state of innocence – in other words, eat from the fruit of the Tree of Knowledge."

This inefficient method of working and teaching is quite often broken away from by ballet teachers who, unconsciously, through ignorance of the exact technical structure, teach movement from the starting point of their own understanding of dynamics and semiotics. From the point of view of artistic and dance requirements they often achieve better and more convincing results. Nevertheless, this approach is hardly suitable as a methodological or didactic policy, whether for the training of dancers or of ballet teachers. Subjectivity and a high level of empirical experience are of little value for the generalisation and development of a carefully thought-out objective teaching basis and method. Generations of dancers, teachers and choreographers have already acknowledged this necessity; many of them, however, have obviously taken only the proposition of innocence to heart, and have tried through the promulgation of a new doctrine, the omnipotence of the artistic, with no consideration for the psychological–physical features of the dancer's body, to bring the demon to life. Existential orientation and feeling were established as supreme in artistic interpretation. Where once the "soul" was considered lost, it was now seen to predominate. This situation was created by great and superbly gifted dancers above all in the area of modern dance, however, without solving the basic problem. On the contrary, it has led among other things to an artistic development among choreographers and dancers loosely although not inaccurately described as "navel gazing".

The possibilities, methods and propositions of neurocognition and biomechanics can, I believe, help us to find a way out of this vicious circle. As far as I am aware, there is in the present school of classical dance no method that has sought scientific support so ambitiously that it has consistently modified its teaching concept and didactics. In principle we are still teaching along the same lines as our predecessors 50 or 100 years ago. We impart feelings and belief to the students as the basic premise of action, instead of giving them methods to recognise the movement, to implement it correctly by awareness of its inner context and structure. The antagonism to science, so frequently observed in dance, corresponds to the dogma of exclusive artistic sensibility, which is thoroughly disproved by other schools of independent thought. Curiosity over the new, as opposed to the old, reliable, protracted way of proceeding, seems to have been carefully suppressed, with positively striking timidity. In my practical teaching work so far, I had only been able to proceed from a basis of empirical observation and experience. My attempts prior to the fall of the Berlin Wall to access the excellent scientific research results in psychology, biomechanics, sports medicine and the first-rate sporting prowess of the German Democratic Republic (GDR) were hopeless. This entire area was a carefully guarded state secret. By all estimations of art and culture in the GDR, it seemed that dance was not then considered quite such a matter of national priority. Even today I continue to experiment in teaching with various approaches to communicating, memorising and reproducing dance movement, both in training and in the theatre, and I am increasingly fascinated by the possibility, parallel to artistic parameters, of a completely new ballet methodology based on neurocognitive and biomechanical parameters.

One example of this is that one of my students, artistically and physically very gifted and highly motivated, seemed to promise a future as a good dancer. He had only one problem, he could not turn, which, not only for classical dancers, was a catastrophe, as pirouettes are part of the basic equipment of all types of dancer. Every correction and countless attempts were all in vain, and brought us both to the brink of despair. The body simply refused to turn balanced on one leg. Following the experience with ideokinetic training detailed at the beginning of this account, it occurred to me to stop all our practical training. I asked him to lie down on the floor (as in the previous example, it was very important to achieve the static removal of the feeling of his body weight) and to close his eyes. He then had to imagine a picture of the complete sequence of movement in his head. When he thought he had this picture clear, I asked him to describe it to me. Everything ran smoothly until he came to the decisive moment of the push-off, a highly complex movement procedure. He stammered and said: “I can’t see anything”: I asked him to create the picture again. The results were identical, and as he formulated it: “I have a blackout!” I answered dryly: “Thank God, because exactly there is your crucial mistake.” He had thought that the more precisely he executed the preparation (the movement sequence leading up to the actual push-off) the better would be the ensuing pirouette. This preparation, however, is a completely formal procedure, which has nothing to do with the actual turn. The generation of the turning impulse is the crucial moment. After I had spent several minutes going through the complex generation of this impulse mentally, and he had provided me with verbal descriptions of the activity to prove, so to speak, the quality of the images running through his head, and after we had gone through the various stages from lying to sitting to standing, from slow to fast, I decided: "Now you may turn." He took his position, executed the preparation, pushed off and turned for the first time in his life three complete, slow, clean pirouettes. Some dancers work on this all their lives and never understand it, and we had done it by "doing nothing", apart from a very specific type of concentration. Subsequently this delightful experience came in useful when I made the ironic comment to dancers who were working "unthinkingly", that dance must really be for lazy people, if they were first to think and only afterwards to move.

We collaborated further in this type of mental training for other movement sequences, particularly when I was getting him ready to compete in the great international Junior Competition in Lausanne, Switzerland. Since I was not able to travel with him as would normally have been the case, he had to go alone. When he experienced serious problems during the competition with the execution of a particular series of jumps, he rang me up to ask for my advice. I made him describe everything, gave him the corresponding corrections, he repeated them over the telephone, danced his round on the following day, and came away with the first prize in the Prix de Lausanne.

However, I was soon to learn how careful one must be with generalisations of this kind of mental preparation, in the course of an experiment that went completely differently. I have for several years been teaching courses for ballet and dance teachers. In a course with the theme "Creating Combinations", I showed a dance teacher a brief combination of jumps. These are sequences created by the ballet master or teacher for the class, and they must be constructed according to specific methodological, artistic, pedagogic and musical principles in order to produce optimal results. I asked him to repeat the sequence. He got his legs into such a tangle that he had to stop. Same procedure again. I show, he repeats, then breaks off in the middle. This had the not inconsiderable side effect that the teacher had made himself look foolish in front of the other seminar participants, had become completely blocked, and no longer wanted to do the exercise. Obviously, I couldn't leave things like this. I said to him: "No problem, I'll show you this exercise again, but first I'll tell you beforehand how you should try to remember it. Because perhaps your problem wasn't that you don't know the steps, which you may have thought too complicated." I should add that he was a well-trained dancer, and in purely technical terms his body was certainly in condition to execute these little jumps and movements correctly. I explained to him: "So just look at the spatial and dynamic sequence of the movement. Don't try to remember the individual movement details." Absolute silence reigned in the studio, and everyone waited for the outcome of this experiment, which as a parallel to the "doing nothing" method ought to lead by way of "remembering nothing" to success. After I had demonstrated the combination to him once again, and reminded him not to try to recall the details, he stood up and executed the combination faultlessly. The other participants in the seminar applauded, the situation was saved, and I was the richer by a new experience. I then asked him to repeat the sequence much faster. Again he succeeded, and I remembered something the famous Russian piano teacher Neuhaus used to say, when in his laconic fashion he pointed out the link between the thinking process and the manual virtuosity of a pianist: *To play fast means to think fast (. . . and to dance fast!)*. The conscious attempt by the seminar participant referred to above to reproduce the technical and spatial structure of each *single* movement proved not only to be unhelpful, but to disturb his rendition of the whole sequence to the point where he was obliged to break off. If in the first example (pirouette), concentration on the minutest detail was important, here the concept of the sequence was in the foreground. The latter has great significance, particularly in dance training, as dance here reaches back unconsciously into areas of previous movement experience and reproduces them under new, different spatial, dynamic, technical and therefore artistic conditions. Experienced dancers have already mastered this principle, and thus considerably facilitate the acquisition of new choreography. In this manner, the aesthetic, content and musical ideas of the choreographer remain at the beginning of the staging of a new ballet or dance, at the level of a certain immaturity of movement, always the only goal worth striving for (see Chapter 6 by Zöllig, this volume). Technical claims can no longer dominate interpretive obligations, and the dancer remains an artist, and never, in the worst case scenario, an athlete.

As has been scientifically established, listening to the same music aids the process of movement recall. Listening to music also activates areas in the brain that are responsible for movement. In the same way as a feeling for the weight of one's own body can in my experience interrupt thought processes in the ideokinetic method of work, a maximal exertion of strength can also hinder the learning and contextual understanding of new movement. It is essential to take this into account in the learning or correction of movement sequences. The reminder of one's own body might impede the thought process. Maximal use of strength might lead to a similar problem in the initial stages of learning movement and impede precisely the comprehension of the cognitive structure of dance movement. Its repeatability, its free spontaneous or goal-oriented application for artistic interpretation, is rendered considerably more difficult, as the body gives priority to "feeling oriented" function. It should definitely be noted that this process is on the one hand relevant to learning or correction of movement sequences. Experienced and very well-trained dancers on the other hand rely quite rightly on the application of their technical resources and even more of their feelings subconsciously to summon up established and rehearsed sequences of movement, which are already stored in their movement memory banks (or movement repertoire;

see Chapter 8 by Calvo-Merino, this volume). This is why I very often get my students or dancers to "mark" the movement with a maximum of 50% of energy, simply so that I can see the movement impulses, which already provide me with a complete evaluation of the truth. At this point, an interesting reaction takes place in the dancer. The vehement exertion of energy, the "learning by doing" method, often leading to inexact and unclean execution, disappears, and the dancer has to regulate movement by means of a *conscious* thought process. Some students have hated me for this method, as it is a natural human tendency sometimes to try to solve problems, not by ratiocination, but by striking out.

In the course of attempting to optimise learning, memorisation and reproduction with the help of ideomotoric or ideokinetic working methods, I have found myself, mainly on the basis of movement analysis that I was necessarily obliged to complete, more and more frequently thrust into the area of biomechanics, the architecture of movement and its internal integration, and I arrived at the realisation: The clearer the movement structure, the easier it was to perceive its internal architecture, and the easier became its cognitive acquisition. This brought a completely new principle of learning to the method of teaching classical dance that I had evolved. The approximately 450 steps or elements of the complete canon of classical dance represent a treasure of enormous value, but on the other hand there is great danger of the standardisation of artistic movement. From this variety of classical steps, I have filtered out the principles of movement that form the basis for the execution of single steps or sequences of movement, and achieved a further simplification and reduction to, in total, seven elements. However, to avoid any possible misunderstandings: a precise knowledge of the canon of classical dance is in any case the *conditio sine qua non*! These seven basic elements only serve to make possible a greater clarity and simplicity in teaching, development and correction, and this not only in classical dance. This is because the working out of the canon of classical dance has as its goal, not the mechanical learning of the external form of these steps, but instead the disclosure and both cognitive and physical acquisition of the context of all movements. These elementary movement principles are of so basic a nature that they are of essential significance to every dance style and technique.

The term "classical" no longer applies to the aesthetic of such "classics" as *Swan Lake* or *Giselle*, but, by means of a revelation of internal structure, to every form of dance. Classical dancers trained this way are able to develop a great affinity with modern dance (which is confirmed by several concrete examples in the course of my teaching activity). The enrichment of classical dance by interdisciplinary cooperation and research in the areas of neuroscience, psychology, biomechanics and philosophy could bring a completely new quality to the teaching of classical dance, and I am convinced that it would bring to an end the ever present antagonism between classical and modern dance. Dancers and teachers need in their actions and movements to take the following premise much more to heart than they have hitherto done: *Learning to dance means learning to think!*

Reference

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6 Searching for that "other land of dance"

The phases in developing a choreography

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How do I see the art of choreography?

Hans Züllig, for many years Head of Dance at the Folkwang School in Essen, proposed the following definition of the art of choreography: "We all feel something, but the big secret is to find just that form of movement that will touch something inside another person" (Züllig, 1999, p. 20). In my work as a choreographer, I seek and create movement. Developing a choreography is a process of exploring the theme, finding a statement, and developing and defining its credible expression in the language of movement. Movements and scenes are found, and the dance company implements these in different formations. These are then explored and tested precisely during the process of developing the choreography.

What do I draw on when creating a choreography?

I am a seeker of movement. I am searching continuously for ideas, suggestions, and inspirations. But what can I fall back on as a choreographer that enables me to find my own new ideas and movements time and time again? How do I continuously recreate the individual physical expression of my person or my dancer? How do the images for a choreography emerge? How does movement arise? And, as a creator of dance, where do I gain my inspiration?

The "craft" and the traditions of dance

The basis of my choreographic work is the dancing techniques, styles, philosophies, and approaches within the traditions of European stagecraft that I learnt during my training as a dancer and have worked with ever since. Every period and every culture produces its own dance. Each epoch also expresses itself in forms of dance: Court dance, ballet, German expressionist dance, modern dance, waltz, polka, rock and roll, jazz dance, hip-hop, break dancing, and even Bavarian *Schuhplattler* (purportedly the oldest living dance form in Europe). I have as many different sources of inspiration for movement as all the human cultures throughout history. The new also has its roots in the old.

Other artistic approaches and perspectives

Because, as the director of my dance company, I am aware of how crucial a multi-faceted artistic environment is for creativity, I also work with guest choreographers, guest trainers, and artists from different fields. These do not just introduce new choreographic insights and different dance techniques to the company; their different work styles challenge my dancers and encourage them to confront the new. Being willing to learn something new and always ready to face new challenges is something I expect of my team and myself. Keeping oneself fit – on all mental levels.

The movement of objects and the human body

Movement is everywhere! Life is full of it and only possible through it. Everything is in movement. Everyday life offers an infinite source of inspiration for movement: facial expressions, gestures and postures, the ways in which different kinds of animal move through the air, on the land, and in water; processes in nature such as a tree swaying in the wind or an erupting volcano; technological and artificial movements such as machines in operation or heavy road traffic. The natural movement sequences of the human body are a major source of my choreographic inspiration. Although our bodies have not changed since time began, it is amazing to see how, over and over again, new forms and ways of moving the human body emerge in ways never seen before. The number of different body languages seems endless; when it comes down to it, each human being has his or her very own.

To be able to understand a movement, it is essential to grasp its logic. You can look at this logic on different levels: as a physical process, in relation to a sequence of movement, and as an element of a meaningful action. Jean Cébron's (1990) guide to the work of Rudolf von Laban (see Box 5.1 in Chapter 5 by Puttke, this volume) integrates all three levels when describing the essence of movement: "Movement is an outcome of the liberation of energy through a muscular response to an internal or external stimulus. This response generates a visual outcome in space and time" (p. 73, translated).

The logic of every movement is constrained by the laws of gravity. Gravity is the force that draws everything toward the centre of the earth. In order to move, this force has to be overcome by energy – this is also the logic of a swinging pendulum. A body drawing itself into a foetal position also follows the logic of gravity. To comprehend a movement, it is important to start with the internal impulses through which it begins. The trigger for a movement may be a feeling, a thought, a memory, or any other perceivable stirring of the soul. The art of finding new movements consists in tapping such internal impulses and carefully working out their bodily expression. This search has much to do with industry and discipline. Creativity is also involved in repeatedly trying out a movement in new ways until it fits. To discover and create movements, it is essential to keep an open mind and exercise one's curiosity.

Every new dance requires a new beginning

Nothing is as precious and precarious as finding ideas. Although the experience and the knowledge acquired during the course of my career as a choreographer certainly provide a good foundation for my work, they may also be a handicap when it comes to searching for hidden ideas. To find new ideas, new movements, I have to break out of routines, to free myself from set ways of thinking and seeing. Otherwise, I shall never be able to discover that which lies hidden beyond the known. In my first choreography, I never even thought that it might become difficult to find new ideas. My resources seemed unlimited. With my fifth choreography, I first became aware of the risk that I might repeat myself. When it came to my tenth project, suspicion became certainty: whether I want to or not, I have to throw myself into every new project. It has to be a new beginning, freely chosen, in order to embark on a new voyage of discovery full of passion and curiosity.

The phases in working out a dance

What you see and hear when a dance is presented on the stage is the outcome of a creative process based on intensive work together with my team. Each member of the team engages in a very intimate discourse, offering his or her own ideas, sequences of movement, and scenes. As the author, I try these out and decide which to use. All the crucial measures for developing and shaping the dance are firmly in my hands. Together with the team of dancers selected for the project, my choreographic assistant, the dramaturge, the set and costume designers, the conductor or composer, I have found my own way of developing choreographies, and I have created an environment that makes this possible. Over the last 10 years, my ideas on what I call the choreographic forum have had a decisive influence on two contemporary dance companies. My goal, both then and now, is to create a place, a laboratory, a niche that permits creativity and the search for movement – a place that inspires movement, permits it, and develops it further.

In the following, I describe the phases I go through when searching for the images, scenes, and movements for a dance. Were I to drop any single one of these phases, a decisive element would be lost. I do not intend to leave anything to chance. The interplay of individual elements needs to be brought into harmony so that everything attains significance. At the end, it is the audience that experiences the visual and acoustic outcome of the choreography and interprets it in a way that turns it into an individual statement.

Phase 1: Exploring the theme and finding one's own access

As a choreographer, it is very important for me to tackle a theme intensively – both intellectually and intuitively. I read the specialist literature, watch movies, and go to exhibitions and museums. I carry out field research; explore locations and their impact, for example, a steel works in Duisburg, the Felix-Nussbaum-Haus at Osnabrück designed by Daniel Libeskind, Hamburg harbour, or the residential tower blocks in the Mahrzahn district of East Berlin. I discuss things with my team, analyse the different aspects of the theme, reach out for and gather together everything I can find on the topic. I look for my own personal access, for the images that fit my feelings and associations. I try to enter the mood I am seeking. At the same time, I want to be open to the ideas, associations, and images of my team. All this collected together forms the initial nucleus of the piece. It serves as the basis for an intensive discourse with my team on the statement we wish to make through our performance.

One of my choreographies, SPEEDLESS, offers a good example of how the interpretation of a theme emerges. This choreography gives an insight into human work worlds from the perspective of time lost. The wheels of productivity are turning faster and faster throughout the world. Economic constraints are making traditional divisions of time into work and rest, or day and night increasingly meaningless. But people are not always able or willing to bear the stress of such "multitasking" in their daily lives – increasingly more has to be done more quickly, more effectively, more appropriately, and more flexibly. When preparing the dance, we asked ourselves the following question: In a daily life no longer fixed in one location, what are the different emphases across the day on time spent working, active leisure time, relaxation, and a functioning social life with one's family and friends? Our work on this theme started with the tension between being efficient and being overwhelmed by excessive demands. Proceeding from this interpretation of the theme, our task was to find movements that would give physical expression to perseverance, efficiency, and stress. Starting with this focus, a dance emerged about how people yearn to have mastery over time.

Phase 2: Building a framework that permits creativity – the concept for the stage set, costume, and music

The outcome of our discussions on the theme is a written concept. The first parameters are set. This concept is a sort of timetable we follow as we develop the dance. The set designer turns up with a model of the stage design. The costume designer arrives with his or her sketches. Decisions are reached on the plot, the various themes, and aspects of the scenes and images we wish to develop, and which improvisation tasks the dancers have to perform. The choice of the theme determines the selection of the music. The musical style shapes the content and the atmosphere of a dance, and the way in which the music is used can be a major dramatic element. For example, the decision whether to contrast the music with the dance or to dance the movement to music can set important accents or decisively shape the statement. The same applies to breaks and silences.

The self-imposed limitation to the artistic scope given by the specification of a concept does not imply any artistic limitation or even confinement. Quite the opposite: the concept delivers creative sources of friction. It is not a straitjacket, but a sort of "open scaffolding" that supports the development of the dance; a discipline that enhances creativity. It is not the concept that dictates the forms to be developed, but the creative work. However, such work only becomes possible within the framework of the concept.

Phase 3: Building a creative environment for the artistic team

While developing the dance scenes, it is necessary to establish a mental space in which creativity can emerge. All the senses have to be addressed at all levels. Dance has to be in the air! The rehearsal room becomes a playground, a space for exploration, a meeting place in which everybody involved in the production is called on to exchange views, to be creative, to suggest ideas, to stand up for what they think, to go beyond the surface, to seek and give inspiration. The cooperation with guest choreographers, guest trainers, and artists from different fields is an important element here. They introduce new aspects, and challenge the team to adopt new perspectives and ways of working.

My task is to inspire and motivate my artistic team. They should be ablaze with the theme! I believe that everything that shapes this mental space also influences the dancers' creativity. The working climate, each choice of music, every discussion on a theme, each improvisation that we demonstrate to each other, each text, in short, everything we do and everything we allow to enter leaves its traces and influences our research. The most important thing for this improvisation phase is that each individual should be free to try things out without embarrassment. They need to feel secure. Therefore, while we are improvising, nobody else is allowed to enter rehearsals. Trying things out in the rehearsal room leads to lots of surprises, lots of new discoveries. Integrating these discoveries and ideas, taking them further, embedding them within the process, and being open for change are very important. The spontaneous actions of the dancers generate many new ideas and impulses that are simply the product of that moment in time. For example, one of my Italian dancers performed an improvisation on sexuality in advertising. He clutched two mozzarella cheeses to his naked chest, proudly presenting his breasts. Using his eyes to flirt with the audience, he squeezed the balls of soft cheese, bowing his head to eat them sensuously from between his fingers. During the development phase, I am always aware that everything can change at any moment. Everything that happens during rehearsals influences the artistic production. Working in a group of 14 people for 8 hours every day at this level of intensity – both mental and physical – is a demanding job. This sort of cooperation calls for a great deal of self-discipline, social competence, and empathy from the dancers and the artistic team. This teamwork and its intensity are in many ways also decisive for a dance company's charisma on the stage.

Phase 4: Improvisation – finding ideas, movements, and paths through space

I challenge my individual dancers to contribute their own authentic feelings and ideas to the development of a dance. I assign them a task and demand a personal response. This makes my dancers into co-authors of my choreographies, and their personal ideas make a decisive contribution to their design. Using props, voice, language, or other dancers, they are free to bring forth their own ideas and associations. For example, one dancer expressed the theme of being overstressed by moving through space with 15 chairs balanced on his back; another multitasked by balancing on one leg on a chair while simultaneously gurgling the old German folksong *Ein Männlein steht im Walde* (*A Little Man Stands in the Forest*; Hoffmann von Fallersleben, 1843).

The body as theme also inspires my visual ideas and fantasies about movement. It is the dancer's instrument. Dancers have a very concise awareness of their body, the parts of their body, indeed, every fibre of it. They are used to interacting with their body, and they perform trained movements very mindfully. The body possesses an enormous reservoir of movements. My interest is in seeking out the limits of the human body, to explore it in depth. What can a body achieve – technically in terms of jumping power, in the height and virtuosity of turns; conditionally in terms of endurance and speed; or emotionally through, for example, painful shivering or euphoric laughter?

For every dance composition, I use my own movements to demonstrate the combinations of steps I want. I search for these movements alone in the rehearsal room. This exploration helps me to grasp a theme physically and understand it. Sometimes, I ask my dancers simply to lengthen my sequences of movements or to change their tempo and dynamics while leaving the form unchanged. At other times, a sequence of movements provides a basic element from which a duet can develop. In response to my combination of movements, a dancer seeks a new movement that a second person can dance. One can explore movement when working with a partner or with the floor through all different kinds of contact. The skin, the body's envelope, is a sensitive organ. The whole body is an organ of touch. The members of my company come from a variety of different countries, have been brought up in different ways, and have different social backgrounds. I work with dancers from Australia, Costa Rica, Ecuador, Germany, Italy, Japan, Portugal, Russia, Sweden, and a host of other countries. That is a further inestimable source of creative inspiration. When improvising with movement, I have come to realize that each single person has his or her own style and individual form and dynamic of movement. There is no single, universal expression of sorrow or joy. Each individual grieves in a different way; has a different image of laughing and being happy. Ten dancers will find at least 10 different ways to express boredom, anger, or being in love. It is a rich and inestimable resource that my dancers bring to the choreographic work. Frequently, an improvised scene taps the essence of the expression. The humour and the drama simply take the right course. Making this replicable, finding the same forms of movement again, requires precise analysis. We record all improvisations with a DVD camera. Being able to catch and identify the successful moment so that we can refine it precisely at a later time is an important element in the production of a choreography.

Phase 5: Fixing and fine tuning – conceiving movements, scenes, and ideas in terms of sequences and structures; working them out in detail, and rehearsing them

Only 5–7% of the ideas developed during the improvisation phase will actually end up in the final production. We collect one to two thousand ideas for each project. As the choreographer, I have to check very carefully to see which scenes are unique and can thus command the stage. I generally drop ideas that can already be found in past productions or have been used elsewhere. The sequences of steps and the plot are fixed for the complete production. Together with the dramaturge, I examine the contents and fit them into the broader dramatic context. The assistant choreographer makes sure all the dance steps are correct. Movements are honed, the synchronicity of group choreographies is rehearsed, and sequences are coordinated and fixed in space. Once dancers have mastered a movement, they know exactly what they are doing. They understand the intention, the form, the dynamics, and the temporal and spatial structure of the movement sequence. They begin to play with it and can interpret the fine nuances of expression.

Phase 6: From rehearsal to the stage – with the set, costumes, props, lighting, and sound

The scenery will now be built on the stage. Together with the dancers, dance sequences have to be adapted to the new spatial dimensions. To complete the production, a lighting concept is developed and implemented. Sound, costumes, and make-up arrive, creating a first impression of the work as a whole. All sequences must be perfect before the dress rehearsal.

Epilogue: What we have to seek – that "other land of dance"

What am I looking for in my work as a choreographer? That is hard to put in a nutshell, because creative work is always searching for what is new, unknown, and completely different. And there are no words for this, let alone a formula. Perhaps the closest one can get is to describe it as attaining an understanding, a contact, or a touch that does not occur at the level of verbal speech but through dance. There are many things I can recount much more exactly with dance than with words. That is why my work seeks to find the personal expression for a feeling and to translate this into movement. The idea is to create a bodily expression that others can understand with their heads, their gut, or their hearts. The expression of my dancers should be authentic. The lengthy analysis while searching for the "essential" movement that will trigger something in the opposite person aims to move the soul of the spectator. This lengthy analysis always starts with a feeling or an idea. Sometimes there is only an "inkling" of how a movement might become manifest. A melancholy feeling when listening to *Waltzing Matilda* becomes a memory of my grandfather, of the story of his life. This memory evokes images that develop into movements. Sometimes, it is chance alone that delivers the decisive impulse. Finding one's own way to approach a theme can be like pushing open a locked gate leading to a secret hidden country – that Other Land of Dance!

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7 Overcoming the dyslexia barrier

The role of kinesthetic stimuli in the teaching of spelling

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Significant research in the 20th century has led many educators, psychologists and neurologists to the conclusion that movement of the human body is essential as a facilitator of cognition and thus academic success. This chapter discusses a kinesthetic-based approach for overcoming dyslexia: the *kinematics teaching methodology* (KTM).

The chapter opens with an overview of theoretical and research findings conducted in the areas of intelligence, mathematics pedagogy and dance. The foundation of the kinematics teaching methodology is described, followed by an example for teaching spelling. A commonly asked questions section addresses assumptions about learning and teaching with KTM. The chapter concludes with final thoughts about future research that will hopefully improve instructional strategies at the classroom level.

Research and theoretical foundations of the role dance and movement play in learning and task mastery

During the 20th century, significant research in areas of neurology, psychology, dance education and mathematics education revealed the functions, importance and characteristics of the use of movement and dance in cognition and learning. The following section highlights these theoretical and research foundations and serves to explain the foundations of movement-based teaching and KTM.

Howard Gardner, a Harvard University researcher, recognized the importance of movement in learning and human function in his *Theory of Multiple Intelligences* (1983). Gardner identified seven intelligences, each of which allows an individual to develop high cognitive skills in that particular area. The seven intelligences Gardner names were *logical-mathematical*, *musical*, *linguistic*, *spatial*, *intrapersonal*, *interpersonal*, and *bodily-kinesthetic*. Gardner identified *kinesthetic intelligence* in his book *Multiple Intelligences: The Theory in Practice* (1993) and defined it as the "ability to solve problems or to fashion products using one's whole body, or parts of the body" (Gardner, 1993, p. 9). When referring to the application of his work in the field of education, Gardner argued that because of the variety of intelligences, teachers should identify students' dominant intelligences to determine which teaching strategies and learning activities will facilitate the desired understanding.

Research in dance education has provided additional foundations for the role dance plays in learning and cognition. Dance educator and philosopher Margaret H'Doubler recognized that the intuitive movement of the body generates an opportunity for the brain to explore, rationalize, judge, compare and analyze the information generated by the body. (Margaret H'Doubler did most of her work in the 1930s and 1940s; the current article was based on a presentation given in the mid-1960s and was included in a collection of essays written by various dance educators throughout the 1960s and 1970s, edited by Dennis J. Fallon and published in 1978.) She added that teaching that allows children to be creative as they dance contributes to the fullest development of personal growth (H'Doubler, 1940).

Researchers Diane Hohl and Carla Smith (1996), who looked at movement activities as a method for teaching geometry concepts to young children, concluded that kinesthetic learners were most able to use such activities to further their understanding of the curriculum taught. Researchers Wendy DeGeest and Linda Wills (1992) looked at the recognition and retention of geometrical structures of nursery school children. They concluded that retention was four times more effective for children who were taught with creative movement activities. Additionally, they noted that children who learnt effectively through movement developed a high degree of enjoyment and enthusiasm towards learning.

Dance educator Ann Green Gilbert conducted a study that aimed to discover whether movement activities can be used to directly increase students' learning of language art skills. She concluded that there was "a direct relationship between the amount of movement used by the classroom teacher and the percentage increase of students' tests scores" (Green Gilbert, 1979, p. 7). The class that showed the least improvement used dance activities for only 15 minutes per week, while the class that showed the most improvement used dance activities for 15 minutes per day. Green Gilbert identified additional areas where the daily use of movement helped students increase their cooperative behavior between the genders; increase bodily control that improved spatial awareness (some hyperactive children were better able to control themselves); increase students' motivation towards learning and taking active participation during lessons; and increase creativity. She also noted that there was a change in teachers' attitudes towards certain children, specifically, teachers were better able to assess students' learning, which contributed to their overall assessment of children's cognitive abilities.

Psychologist Rita Dunn has written extensively about the importance of matching learning styles to type of teaching strategy to maximize learning (Dunn, 1983a, 1983b, 1983c). Dunn defines learning styles to include 21 different elements among which are auditory, visual, tactile and kinesthetic.

Kinesthetic learning style was identified by the preference to learn by engaging in a physical activity and performing physically energetic tasks. Dunn's recommendation for students who are identified on the *Learning Style Inventory* (Price & Dunn, 1997) as kinesthetic learners is to incorporate in the teaching instruction body games, physically engaging activities, and tasks requiring active socializing with others such as engaging in conversation (Dunn, 1983b, 1983c). Relevant research in neuroscience is discussed at length in Chapters 9 and 8 by Cross and Calvo-Merino (this volume) and will therefore not be repeated here.

The issue of best approaches for teaching children is the center of *constructivism*, a philosophical theory that holds the premise that obtaining knowledge is the result of a conscious cognitive activity taking place through active personal experience (Confrey, 1990; von Glasersfeld, 1984). Confrey (1990) explains that the origins of constructivism are found in the work of Jean Piaget, who recognized that some children's process of constructing mathematical understanding did not always parallel the process of adults with experience in mathematics. Piaget pointed out that some children lack both the understanding of mathematical processes and the techniques and methods used to construct different forms of arguments (Confrey, 1990, p. 109). Piaget's research laid the foundation for a new school of thought addressing the issue of knowledge construction in general and in mathematics education in particular. Constructivism, as it is applied in mathematics education, accepts three assumptions regarding the process in which mathematical knowledge is constructed: first, the construction of knowledge is not obtained through passive listening and rote memorization, because knowledge is not an iconic set of data, it is the freedom to choose from a variety of ways, physical and other, for acting and thinking that is essential to fulfill one's goals (Pirie & Kieran, 1994; von Glasersfeld, 1987, 1990, 1995a). (The constructivist philosophy does not distinguish between abstract understanding as it is constructed in mathematics and geometry, as geometry is a sub-area of mathematics. In this section, therefore, abstract mathematical thinking refers also to the understanding of abstract geometrical concepts.) Second, knowledge is obtained through the opportunity to think sequentially in a problem-solving situation that requires abstraction (von Glasersfeld, 1990). Third, knowledge is obtained by the use of language as a guiding tool for developing understanding, investigation of concepts and ideas, rather than merely a vehicle for transporting information (Cobb, Yackel, & Wood, 1992; Pirie & Kieran, 1994; von Glasersfeld, 1990).

Researchers have expanded on each of these assumptions in order to increase the applicability of constructivist theory in the mathematics classroom. This was done by considering and analyzing meaningful knowledge construction from three perspectives: an *active learning* process, a *problem-solving* process, and a process obtained by *social interaction*. Ernst von Glasersfeld writes that mathematical knowledge is gained by allowing a person to obtain an actual physical experience that serves to compare abstract knowledge previously constructed with current real-life experiences (von Glasersfeld, 1995a). He provides an example of the physical experience needed to construct a meaningful understanding – an infant's intuitive way of making sense of the world by moving the entire body (von Glasersfeld, 1995a). In the past, von Glasersfeld claimed, psychologists overlooked the whole body interaction and focused only on the motion of the arms, while it is the whole body's motion that facilitates understandings (von Glasersfeld, 1995a, p. 371).

Pirie and Kieran (1994) argue that much mathematical understanding comes from the ability to construct and work with mathematical ideas that are not dependent on physical context and that are expressed symbolically. To help students achieve mathematical power, the teaching should emphasize the learners' process of constructing a meaningful understanding of mathematical concepts rather than presenting students with formalized ideas (Pirie & Kieran, 1994, p. 39). These researchers advise that accepting the perspective that knowledge construction is an ongoing process, occurring over time and defined by experience and exposure to a variety of teaching approaches, will assist teachers in helping students construct mathematical understanding (Kieran, 1994, p. 589). Acceptance of this view of the nature of knowledge construction led researchers to examine new teaching practices in the mathematics classroom. Such practices include providing students with the freedom to develop mathematical relationships by engaging in social communication, allowing students to initiate and pursue highly intuitive situations (Cobb et al., 1992), and having students pose, identify and solve issues they see as problematic (Anderson & Piazza, 1996; von Glasersfeld, 1990, 1995a, 1995b).

Constructivism represents the notion that expressed knowledge demonstrates an individual's subjective interpretation of real-life situations (Steffe & Weigel, 1992), which implies that there are a variety of ways in which a solution can be obtained (von Glasersfeld, 1995b). It is this assumption about the nature of knowledge that brings researchers to see problem-solving as a crucial part of creating a constructivist environment in the mathematics classroom (Cobb, Wood & Yackel, 1991; Confrey, 1990; von Glasersfeld, 1987). Problem-solving is viewed by Cobb et al. (1991) as the asking of students to share their thought processes through social interaction. The researchers explain that asking students to verbalize the nature of their thoughts helps them formalize their mathematical understandings (Cobb et al., 1991). The researchers suggest several ways for applying problem-solving in the mathematics classroom. One alternative, for example, is to develop activities that are relevant to the students' interests and apply them in context (Anderson & Piazza, 1996). Another alternative is to provide these activities to groups of students and to individuals who will work on ways of presenting their thought processes (Cobb et al., 1991).

According to the constructivist perspective, knowledge is established when cognitive processes are stimulated through social and cultural interaction (Cobb et al., 1991, 1992). This view has led researchers to argue that to know means to be able to participate in a social interaction, and that there is one main strategy that encourages such knowing – communication as a tool for teachers and students to negotiate ways of interpreting verbal and mathematical language (Cobb et al., 1991, 1992; von Glasersfeld, 1990). The means for constructing knowledge through social interaction and communication include discussion that requires students to verbalize their mathematical thinking; that is, to explain and justify proposed solutions and resolve conflicting points of view. Engaging in such communication helps students to construct a common language as a tool for talking about mathematical ideas (Anderson & Piazza, 1996; Cobb et al., 1991). Ernst von Glasersfeld (1990) elaborated on the issue of using communication in the mathematics classroom. He argued that effective communication is created when both parties understand the meaning of the words used. A common problem, he claimed, occurs when each party believes that the words used have a fixed objective meaning, which results in misunderstanding and misinterpreting the language used. A strategy for solving this problem, von Glasersfeld suggested, is for both sides to view their own statements as expressions of a subjective world, which results in the ability to expand on what is heard.

The application of tactile activities such as writing and the use of manipulatives are commonly found in classroom instruction. Kinesthetic-based activities, however, are far less commonly used in daily teaching of the general student population or those diagnosed with dyslexia. Instructional strategies recommended for use with dyslexic students rely heavily on visual and auditory processing (both areas that were found to include neurological deficiencies that prevent the efficient and quick learning of spelling). Prior to discussing the *kinematics teaching methodology* (KTM), an application of kinesthetic activities in overcoming dyslexia (among others), an overview of the disability, its definition by several international groups, and its causes and effects on academic achievement will be included.

Dyslexia – a neurological barrier to high academic achievement

International reports indicate that about 15% to 20% of the population demonstrate difficulty in reading, with a specific diagnosis of dyslexia. If you have taught in the regular classroom, you may have experienced the impact of dyslexia and other learning disabilities on the learner and the teacher. You may also be familiar with the impact on the child's emotional development as a result of their daily struggle with reading, or your own frustrations as you have contemplated how to best help these students.

Dyslexia is usually diagnosed in the late school years, sometime as late as at college level. This leaves many students underserved, hindering their academic success. This also means that unless teachers are well trained to teach students with this disability, all involved are likely to feel trapped in an ineffective instructional reality. The end result is likely to be students developing feelings of inadequacy, poor self-esteem, and low motivation towards learning, and high frustration levels on the part of teachers. Neither is a desired result of years of schooling.

Definition, causes, effects on academic achievement

The International Dyslexia Association defines the disability as a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede the growth of vocabulary and background knowledge (see the International Dyslexia Association website http://www.interdys.org/ewebeditpro5/upload/Definition_Fact_ Sheet_ 3-10-08.pdf).

The British Dyslexia Association defined the disability as a specific learning difficulty which mainly affects the development of literacy and language related skills. It is likely to be present at birth and to be lifelong in its effects. It is characterized by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities. It tends to be resistant to conventional teaching methods, but its effects can be mitigated by appropriately specific intervention, including the application of information technology and supportive counseling (see British Dyslexia Association website http://www.bdadyslexia.org.uk).

The Dyslexia Association of Ireland explains that dyslexia is a specific learning difficulty which makes it hard for some people to learn to read, write and spell correctly. On the Dyslexia Association of Ireland website the recent Report of the Task Force on Dyslexia (2001) suggests the following more scientific definition: Dyslexia is manifested in a continuum of specific learning difficulties related to the acquisition of basic reading, spelling and/or writing skills, such difficulties being unexplained in relation to an individual's other abilities and educational experiences. Dyslexia can be described at the neurological, cognitive and behavioral levels. It is typically characterized by inefficient information processing, including difficulties in phonological processing, working memory, rapid naming and automaticity of basic skills. Difficulties in organization, sequencing and motor skills may also be present (this section is taken directly from the Dyslexia Association of Ireland website http://www.dyslexia.ie/dysexp.htm with minor spelling changes to grammatically adhere to American spelling rules).

The exact causes of dyslexia are still not completely clear, however comparative studies of the brain imagery of dyslexic persons and those who do not have dyslexia show differences in the way the brain of a dyslexic person develops and functions. Moreover, most people with dyslexia have been found to have problems with identifying the separate speech sounds within a word or learning how letters represent those sounds, a key factor in their reading fluency. Dyslexia negatively affects the academic achievement of students whether they are in kindergarten or twelfth grade. The core difficulty is with word recognition, reading fluency, spelling, and writing. Some dyslexics manage to master early reading and spelling tasks, but as the reading load and difficulty level increases with the years, these strategies become insufficient. This is notable when faced with complex language skills such as correct sentence and phrase construction, understanding of challenging textbook material, and writing essays. In the early school years, dyslexic children often confuse small words such as "at" and "to", may reverse letters such as "d" for "b", and may reverse words such as "tip" for "pit". They may also demonstrate difficulty in reading single words on flashcards and learning the connection between letters and sounds. Students with dyslexia may also experience problems with spoken language, even after they have been exposed to good language models in their homes and good language instruction in school. They may find it difficult to express themselves clearly, or comprehend fully when spoken to. Such language problems are often difficult to recognize, but they can lead to major problems in school, in the workplace, and in relating to other people. The effects of dyslexia reach well beyond the classroom. Undiagnosed and untreated dyslexia usually causes learners to develop poor self-image, high levels of anger and feelings of worthlessness because of repeated low achievement in school. After experiencing a great deal of stress because of poor academic achievement, learners are likely to become discouraged about continuing in school or learning in general.

The negative effects of dyslexia on students' academic success, motivation to learn and self-image are well documented in the literature. Instructional strategies that were identified to address this disability rely mostly on audio and visual stimuli, and establishing repetition of sequences and routines. One area that was overlooked until 1999, was the use of kinesthetic intelligence in overcoming this disability. The following section introduces the application of kinesthetic intelligence in overcoming dyslexia. The teaching methodology is titled the *kinematics teaching methodology* and was created based on two research studies and years of teaching and observing dyslexic students.

The kinematics teaching methodology (KTM): A strategy for overcoming dyslexia

The theoretical foundations of the KTM are anchored in *constructivism*, Howard Gardner's *multiple intelligences theory*, and *learning styles* work defined by psychologist Rita Dunn (see above). My interest in the field of kinesthetic intelligence and dyslexia rose from teaching this student population and observing my brother, a talented car race mechanic, go through humiliating experiences in 9 years of elementary and middle school. My brother's dyslexia was not diagnosed in time and was not treated appropriately.

During his school years he was never able to complete a written test on time and often was put down by his teachers for failing on writing assignments. As a teacher, I have always wanted to make sure that my students experience the feeling of success as they master reading and comprehension skills, and that they take advantage of effective instructional strategies. Experiencing first hand my brother's frustration and my own students' struggles led me to want to find a way of overcoming dyslexia.

KTM grew out of my dissertation study that identified the behavioral responses of fourth grade kinesthetic learners as they were taught geometry concepts through dance. I then designed and implemented a second study that aimed at identifying whether instructional strategy used for teaching addition, multiplication and geometry concepts to fourth grade students played a role in these students' academic achievement. This study was funded by the Florida Department of Education, with the assistance of Orlando Ballet, our partner that hosted the training. Participating teachers were all employed by the Orange County School System, Florida, USA.

The study included 500 fourth grade students who were taught the State's mathematics curriculum over a period of 2 years. The experimental group was composed of students who were taught by teachers who attended mandatory 80-hour professional development training. The training was offered as a concentrated 2-week full-time seminar over the summer of 2001, just prior to the beginning of the academic year. The control group was taught by teachers who did not receive the KTM teacher training and did not implement kinesthetic or dance activities in their classrooms. Pre- and post-tests were administered by all teachers at the beginning of the academic year, at the end of each unit and, with the same intervals, the following academic year. Test scores were recorded, and the analysis focused on the academic performance of the student relative to four factors: *instructional strategy* implemented by teachers, *gender*, *social economic status* of the child's family, and previous *history of learning disabilities*. Results of the study are displayed in Table 7.1.

Students diagnosed with cognitive disabilities such as attention deficit/hyperactivity disorder (ADD/ADHD) made up 2.4% of the entire study population (25% females). This group of students was able to increase its overall scores from an accuracy average of 68% before being taught with KTM to an accuracy average of 79% after being taught with KTM. This is an improvement of 11 points from the pre-test, to the post-test, or an improvement from a grade of C to a grade of B. No data were available from the control group.

The overall mathematics performance of the participating students in this study was measured at three levels: proficient, basic and below basic. This is similar to the measurements used by the National Center for Education Statistics of the U.S. Department of Education. Following is a comparison of the mathematics achievement of the participating students in this study with the national statistics. In this study, after KTM was implemented, 70% of the students were at the proficient level, 12% at the basic level and 18% at the

Table 7.1 Results of a study of KTM teacher training effects on fourth grade students' learning progress in mathematics (adapted from data by Florida Department of Education)

	Accuracy level in the pre-test (experimental group) (%)	*Accuracy level in the post-test (experimental group) (%)*	*Increase from pre- to post-test (experimental group)*	*Increase from pre- to post-test (control group)*
Average score in overall mathematics	53	82	29 points	< 5 points
female students	63	87	24 points	
male students	61	82	21 points	
Average score in multiplication	62	82	20 points	< 10 points
Average score in geometry	42	79	37 points	< 10 points
female students	41	73	32 points	
male students	44	84	40 points	

below basic level. Nationally, in the year 2000, when KTM was not implemented, 26% of the students performed at the proficient level, 43% performed at the basic level, and 31% performed at the below basic level (the data are taken from The National Report Card 2000, The National Center for Education Statistics. U.S. Department of Education. NCES 2001–518). These numbers speak for themselves in regards to the advantages of using KTM as a teaching tool that is effective for most students

Analysis of the data together with teachers' and students' testimonials, led to the conclusion that the use of dance in the classroom could also be beneficial for teaching students who have dyslexia. This is because, in my view, KTM assumes that movement is an innate ability of humans, one that is essential for learning and understanding. As such, understanding of abstract concepts as well as the ability to remember arbitrary sets of information such as spelling, relationships between letter combinations and the sounds they make, depends on a meaningful use of movement. KTM uses significant verbal communication as a tool for transforming sensations generated by dance into abstract concepts.

I was fortunate to have the opportunity to work one-on-one with a sixth grade student who was diagnosed with dyslexia and who was failing in school. I used KTM with her as a tool for strengthening spelling and phonemic awareness. At the end of a 5-week intensive summer program during which we met daily for 180 minutes, my student was able to score 100% correct on her final spelling test that included 57 words. Hundreds of observation hours of students and analysis of their learning led to expanding KTM to include strategies for teaching reading and phonemic awareness. Interviews conducted with the students and teachers who participated in the

Orlando study revealed the reasons and ways in which KTM helps to enhance students' academic achievement and motivation to learn. To summarize:

- KTM offers learners the freedom to express themselves creatively and individually. Specifically, it builds on auditory, visual, tactile and kinesthetic activities in order to stimulate the brain throughout the learning process. The opportunity to work individually allows students to develop understanding and plan for their classroom presentations.
- KTM encourages learners to develop and demonstrate their work in small groups as well as in large group sessions. This leads students to develop high communication skills, effective listening skills, and with appropriate adult direction, the tools for working supportively with each other. (The small group section of a lesson could also be referred to as the use of centers, where students work on a specialized task in different areas of the room.)
- KTM requires teachers to frame assignments clearly and give students the opportunity to clarify and justify their work. Teachers give immediate feedback to students as the lesson progresses, which empowers students. It also allows teachers to redirect if misconceptions become apparent. Teachers are agents for positive and supportive learning by acknowledging students' efforts and providing probing questions that further students' knowledge.
- KTM provides learners with the opportunity to use their high energy levels during class time in a constructive and well-guided way. The direct result of this is students who are constantly engaged in learning and are empowered because their physical and cognitive needs are fully stimulated in a positive manner.
- KTM avoids barriers to effective learning and cooperative behaviour by including physical activities that require lots of movement in the classroom. The most evident characteristic of KTM is that students are not required to sit still for long periods of time while a teacher gives a lecture. The direct effect of this approach is a stress-free classroom, where students willingly follow instructions and are engaged in learning content matter.
- KTM facilitates the construction of strong comprehension of content by allowing learners to demonstrate their knowledge and understanding verbally and physically.
- KTM overcomes the inherent bias of written tests by offering alternative ways of measuring students' knowledge and understanding, by allowing students to verbally and kinesthetically demonstrate their knowledge (measurable criteria for assessing knowledge that is expressed via kinesthetic activities are discussed later on in the chapter).

KTM – a nine-step teaching and learning process

The following section spells out the nine-step pedagogical process that is required for correct facilitation of KTM throughout a lesson. Skipping a step may deter learners from achieving their highest level of academic ability. The nine steps illustrate the lesson structure, progression, concepts students must master, and specially designed activities.

Step 1: Verbal and visual introduction

Instruction should begin with a verbal explanation of what is about to be learnt and performed. Introduce your lesson in just two or three sentences. Use the blackboard or printed material as a reference clearly posted on the wall. The introduction should include a question that probes students to draw on previous knowledge or experience. This process will help new knowledge and understanding connect to existing knowledge.

Step 2: Creating an individualized shape bank

Students begin to develop a “shape bank” and a “transition bank”, both of which will be used as foundations for learning (compare to the perspective on motion planning presented in Chapter 2 by Rosenbaum, this volume, according to which goal postures are defined first, and movements are specified in a second step as transitions between goal postures). A shape bank is formed by students creating shapes (with their bodies) that they like. The bank should include shapes in high, medium and low level in space, and shapes that can be characterized as small, tall, wide, on-one-foot, and while in sitting position. These shapes should be documented on paper by the learners by drawing stick figures, so that there is a record of the shapes for later use.

The purpose of developing a shape bank is to help students establish a high level of confidence using their bodies while moving in space. To encourage this process, play instrumental music, instruct students to dance freely in space. When the music stops students should “freeze” in space. The *freeze concept* is a still moment in time that requires learners to hold their position in space without any motion, that is, to create a shape. The *freeze motion* is essential in order to develop students’ attention, concentration, and ability to adhere to their own intuitive movement choices, and to learn to control their bodies such as avoiding a fall. Repeat the dance/freeze process several times and every time define the shape students are to assume on the next freeze. At the end, ask students to document their shapes on paper with the stickman sketch (Figure 7.1).

The stickman should represent the shape of the body in space. A sitting figure that tucks her head between her legs is displayed in Figure 7.2. A jump in the air while the arms are stretched above the body and straight into the air will feature the shape of the body relative to the floor line such as illustrated in Figure 7.3.

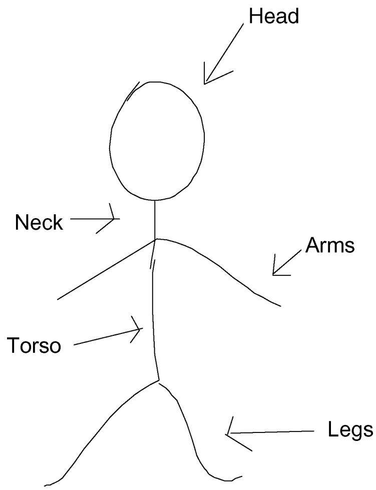

Figure 7.1 Stickman sketch.

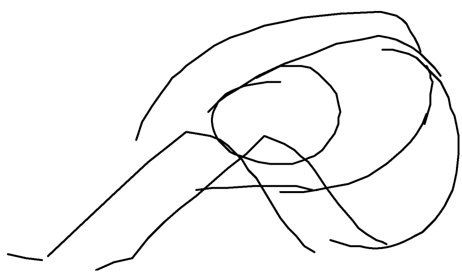

Figure 7.2 Stickman sketch of a sitting figure tucking her head between her legs.

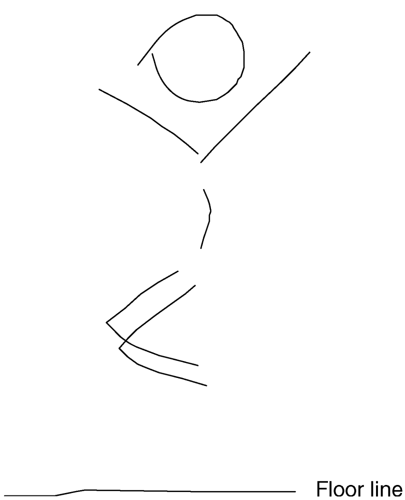

Figure 7.3 Stickman sketch of a figure jumping in the air.

Documenting shapes on paper is important for helping students develop an understanding of their own body's motion and spatial awareness (i.e., the amount of space their motion actually occupies in the surrounding space). Documentation is also important for establishing strong visual memory of three-dimensional shapes as represented on a two-dimensional mode, such as paper. This skill is particularly important when studying geometry in elementary school. Finally, such documentation helps instill confidence in students' own writing skills because of the extra practice these activities provide in the area of writing.

Step 3: Creating an individualized transition bank

The purpose of developing a transition bank is to first increase the students' ability to dance expressively through space, and to expand their movement expression skills. This is necessary because meaningful learning is anchored in deep physical and emotional experience. For some students, unless they are able to fully engage in the learning process, that is, they can draw on previous life experiences and on their own emotions, and are given the opportunity to verbalize and demonstrate these through movement, the learning experience will be limited.

A second purpose of developing a transition bank is to help students identify different speeds and paths in space, all of which are additional tools for demonstrating their knowledge. For example, a transition from one shape to another can be curved and smooth or as short in time and distance as possible. These types of moves will be later associated with the meaning of words that the learner will attempt to learn to spell. Transitions, just like shapes, should be documented on paper by the learners for reference purposes. Each transition should have its own symbol and students should be able to recognize those symbols and the movement paths they represent. The symbol should appear over the shape. Examples are given in Figures 7.4 and 7.5.

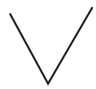

Figure 7.4 Example of a sign representing a sharp transition. The symbol resembles a sharp transition in that its own writing requires a sharp action on the paper.

Figure 7.5 Example of a curved and leisured transition sign. The symbol resembles a curved transition in that its own writing requires the creation of an elongated arch over the shape.

Developing a transition bank requires the teacher to ask students to dance while expressing the qualities such as robotic movements, heavy motion, circular movements, sad emotion, happy and cheerful mood, and hurried motion. The teacher instructs learners to dance while expressing a particular mood. Learners begin to dance as the music plays and freeze when the music stops. Repeat rehearsing the transition bank several times.

Steps 2 and 3 should precede instruction that aims at incorporating movement into the teaching of academic curriculum. This is because understanding shapes and transitions is an essential building block for understanding movement and for building movement confidence (see Chapter 2 by Rosenbaum, this volume).

Step 4: Introduction of curricular content

The teacher presents the information or problem and frames a question to be explored both kinesthetically, by students putting together a dance phrase, and by writing information on paper.

Step 5: Individual and group exploration

The teacher assigns students to work first alone, then in groups of two, three or four. KTM work requires the learners to develop their own kinesthetic movements and documentation in writing. The *vocabulary bank* reflects the accumulated body of words that each learner develops. Students are also required to express their work kinesthetically and orally. This should be done daily and as much as possible throughout the day. This learning process relies on a significant amount of conversation between students, thus teachers should not be alarmed by the level of buzz in the class while students work in groups. Also, it is common for some learners to speak to themselves while learning, which is known in the literature as *self-talk* (see also Chapter 1 by Schack, this volume). Self-talk is an affirmation strategy for evolving knowledge and understanding, and should be encouraged by teachers. On noticing self-talk, a teacher should listen and attempt to identify any misconceptions that she should address at that time.

Step 6: Rehearsing group work

The teacher instructs learners to rehearse their kinesthetic presentation and be prepared to explain it verbally to the entire class. During students' work, the teacher rotates among the groups, making him or herself available to answer questions or provide clarification. The teacher should listen to students' discussions and look for the students' reasoning and thought process. The teacher should provide positive encouragement to students as they work together.

Step 7: Final review and rehearsal

The teacher calls for everyone's attention and instructs each group to rehearse their presentation one last time.

Step 8: Class presentations

Each group demonstrates its work (kinesthetic, written and oral explanation) to the entire class. At the end of each demonstration the group explains their work process. The teacher facilitates a discussion between the presenting group and the "audience" with the purpose of clarifying and answering any questions the "audience" might have.

Step 9: Final performance and summary

The teacher instructs all groups to perform their kinesthetic representations one last time, in unison. The teacher then concludes the session by asking students to summarize key issues and by explaining the homework and providing an example of how KTM should be used at home to further learning of the topic.

KTM in the teaching of spelling – an example

As discussed earlier, the dyslexic student population finds it difficult to interpret correctly and express in writing abstract representations. This student population may also have difficulty correlating sounds with the letters they represent. Note that expressing understanding in writing is not related to expressing understanding verbally or kinesthetically. While dyslexic students may experience difficulty demonstrating their understanding via writing, this may not be the case when they are asked to demonstrate their understanding via kinesthetic or verbal means. Thus, the fact that students are not able to express themselves via writing does not necessarily mean that these students are not able to process the information entirely, but rather, that the channels through which understanding is conveyed need to be versatile in order to accurately portray what students really understand.

Below is a lesson plan with *instructions for teachers*, designed to enhance the teaching of spelling to first and second grade learners. The word taught is MOTHER. The lesson goals are to teach the correct spelling of the word MOTHER, and to build learners' cognitive understanding of the word by developing a graphic organizer that includes all relevant associations of mother figures. By the end of the lesson, students will be able to spell the word mother correctly, discuss their understanding of the word, and explain the relationship between the letter combination and the sounds they make.

Step 1: Verbal and visual introduction

Introduce your lesson in just two or three sentences. Write the word MOTHER in large print on the board. Ask the children to write the word in their notebooks in large print. Emphasize correct spelling of the word by stating aloud each letter in the word. Explain the lesson goals.

Step 2: Creating an individualized shape bank

Ask students to share the characteristics of their mothers. Write the list of adjectives on the board. Instruct students to dance expressively as you read the characteristics. If space is too small for everyone to dance together, divide your students into two groups. While one group performs, the other observes, then the groups switch. At the end of this process, ask students to choose their own shapes that they would like to include in their MOTHER dance. Ensure that the students document their shapes on paper.

Use audio, visual, tactile and kinesthetic means in order to help students make a personal connection to the topic taught. Provide positive reinforcement for students as they participate efficiently and willingly: "I like that you are focusing on the activity", or "This was a very nice move, would you perform it again please?" In order to further cognitive processing and direct students' attention to their own movements, ask them to explain the intent and motivation behind each move. This process will lead students to actively use their vocabulary and search for new vocabulary as needed. This process will also allow students to practice their reasoning aloud.

Step 3: Creating an individualized transition bank

Instruct students to explore transitions that express the qualities of their mothers or other students' mothers. Give students enough time to construct their own transitions and document them in their note books. One example for creating transitions for the word MOTHER is to dance the qualities of a mother such as "forgiving", "understanding" and "is able to listen". These might be drawn as shown in Figure 7.6: forgiving could be represented

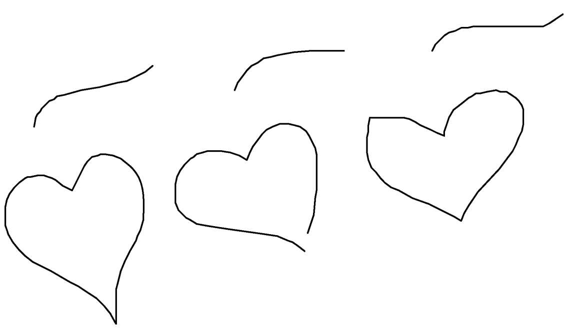

Figure 7.6 Transition representing the quality "forgiving" for the word MOTHER.

by three hearts, as the heart forgives. Three represents the multiple times that mothers forgive, and the curved line above the hearts represent a smooth hand motion to execute that quality as the hand extends from the heart outwards towards an imaginary person.

The qualities of understanding and being able to listen can be expressed by the shape of a face that nods slightly, slowly and gently up and down as the mother listens patiently. In Figure 7.7, the circle represents the face, and the wave next to it represents nodding.

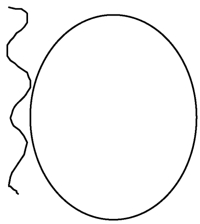

Figure 7.7 Transition representing the quality "understanding, able to listen" for the word MOTHER.

It is critical that students are able to share aloud their reasons for selecting a written shape to represent their thoughts. This process refines the students' verbal communication, reasoning and understanding of the material. Teachers should introduce the concepts of *body visualization* after the students are introduced to the lesson goal. This term refers to the ability to visualize one's motion in space without actual execution. The process of teaching body visualization emphasizes paying attention to details, like the position of each body part at any given movement in time and its location in space. It is this attention to detail that is translated into visualizing the combination of letters as in the correct spelling of a word.

Step 4: Introduction of curricular content

Once all students have created their shape and transition banks that represent the meaning of the word MOTHER, they are instructed to create their own MOTHER dance.

Instructions:

- Express in your own body motion the order of each letter in the word sequence MOTHER.
- Use shapes and transitions from your bank to connect between vowel and consonant to express the meaning of the word MOTHER.
- Rehearse your dance as you are saying aloud both the correct pronunciation of the word and its meaning. Rehearse the dance to be performed both by speaking it aloud, and by dancing it silently.

This process may seem very lengthy, and teachers have commented that they did not feel that they could afford to spend so much time on this process. However, over 10 years of teaching experience I have found that, when KTM is implemented on a daily basis, the process becomes quiet and efficient. Students become accustomed to the routines involved and they are eager to start dancing and become engaged in investigating, asking meaningful questions, reasoning their answers, and making real efforts in creating dances that represent their understanding.

Teachers might wonder if KTM is an effective method for recall, especially during tests that are often time-limited. Observations of kinesthetic learners over time showed that, once kinesthetic representations are rehearsed well enough to become second nature, recall of information occurs by simply visualizing the movement while sitting. In some cases, minimal movement of the arms or torso triggers recall. KTM is currently assumed to assist students establish long-term memory (see Chapter 4 by Bläsing, this volume).

Step 5: Individual and group exploration

Allow students to work on their own to construct their MOTHER dance. Pairing students will be as useful as having students work on their own. Instruct students to document their dance on paper for reference. The documentation needs to include all shapes and transitions that represent both the correct spelling of the word MOTHER and its meaning.

Grouping students in pairs after they have constructed dances on their own will encourage them to do a better job than otherwise, because of the social pressure added by needing to demonstrate a dance to others. Working in couples also allows students to practice observing and being observed in a relatively safe environment, which contributes to their self-esteem. The teacher will have to spend a little bit of time to teach students the rules of observing others, sitting quietly, keeping their eyes on the performers, listening to what the performers are saying, avoiding movement or sharing of comments, and respectfully clapping at the end of a presentation.

The teacher's goal is to encourage students to develop their own vocabulary related to the word MOTHER, based on their experiences with their own mother or other mothers that they have observed or met. All students, but especially those who are young (4–9 years of age) may need additional scaffolding and guiding in order to establish their vocabulary bank. A most meaningful vocabulary bank is created when a teacher asks learners questions that draw on their previous experience, such as: "What memories do you have of your mom?", "Name the first thing that comes to your mind when you think of other mothers", "What do you like about your mother?", "What do you like about your friends' mothers?", "Name one thing that you will always remember your mother for", or "If you needed to pass on any of your mom's qualities to your children, which one would you pass on and why?"

Once students provide answers to these questions, teachers should build on that information by asking them to give examples and reasons for their statements, and synthesize the information they hear. KTM uses this discussion as foundations for the meaningful dance that students will create. Ideally, students will work towards dancing their MOTHER dance expressively, so that each movement expresses a word or a thought discussed earlier.

Step 6: Rehearsing group work

Rotate among the groups, observe and make yourself available if students need assistance.

Step 7: Final review and rehearsal

This is a rehearsal prior to the official performance that is about to take place in the class. The rehearsal includes a verbal explanation of the process, what meaning the group has for the word MOTHER, and the group's performance of the correct spelling of the word.

Step 8: Class presentations

Classroom presentations by each individual group take place. The performing group is in the middle of the classroom with all peers sitting quietly as the audience, either in front or around the room. Each group performs its MOTHER dance and explains how the dance relates to the meaning of the word, and the correct spelling of the word. The teacher ensures that all group members pronounce the word MOTHER correctly.

Classroom presentations are an excellent opportunity for teachers to remind students about strong observation skills, including paying attention to the details performed, paying attention to the group verbal presentation, and taking mental notes of associations this information sparks in one's mind. Once the teacher reminds the audience how to take mental observational notes, sharing of these notes should take place and should be revisited during Step 9 of the lesson.

Step 9: Final performance and summary

Each group demonstrates its work (kinesthetic, written and oral explanation) to the entire class. At the end of each demonstration the group will explain its process and the teacher will facilitate a discussion between the presenting group and the audience with the purpose of clarifying and answering questions the audience might have.

All groups perform their MOTHER dance one last time. If space is limited, divide the students into smaller groups. You will find that students love to observe others as well as performing their own dance. The teacher summarizes the learning process and assigns homework, for example: Rehearse your MOTHER dance and create a FATHER dance for the next lesson. Be prepared to demonstrate your understanding of the correct spelling of these words verbally, kinesthetically and in writing.

Successful implementation

Successful implementation of KTM requires not only understanding of the process, but also understanding of the subject matter. This means teachers must familiarize themselves with the goals and objectives of the subject as defined by their State Department of Education and the national standard of that particular subject. (In the United States, each state has its own mathematics standards, that is, what section of the curriculum should be taught at what grade. The National Council of Teachers of Mathematics (NCTM) is a national organization composed of mathematics educators from across the country, who publish national standards of how to teach mathematics at each grade level based on most recent research in mathematics pedagogy. The United States mathematics standards are available on the NCTM's website www.nctm.org.) Furthermore, teachers must have a specific teaching goal and predetermined activities that are designed for the purpose of teaching that lesson.

Students who have dyslexia find it difficult to intuitively and proficiently translate their abstract understanding to a written form. KTM teaching progression allows students to enhance their writing skills, and it is up to the teacher to include opportunities for students to spell words correctly *after* they have experienced the correct spelling kinesthetically.

Implementing KTM requires time and a particular progression that should be followed carefully. Teachers should ensure that they:

- explain clearly and succinctly the activity and problem to be solved;
- model a short and simple kinesthetic solution so that students understand what is expected of them;
- give students sufficient time to read the activity (if instructions are given in writing) and design a process towards a solution;
- remind students of the importance of documenting the kinesthetic process on paper;
- encourage students to draw on their thoughts, ideas, imaginations and experiences when developing their shape bank and transition bank;
- explain that meaningful learning requires continuous repetition of kinesthetic phrases;
- reiterate that visualization of their own body as it moves in space is required before any movement is performed;
- require students to demonstrate their work by performing the kinesthetic representations to the entire class. Verbal explanation of the movements and how they represent a solution to a given problem is critical for

strengthening the connection between a kinesthetic representation and that given verbally and in writing;

- explain to students that careful observation of their peers will enhance their own performance and success in class;
- encourage students to work together when appropriate, in order to arrive at better kinesthetic and written solutions.

Through this process, all kinesthetic presentations and explanations should lead to a coherent understanding of the problem and its solution as expressed both verbally and in writing.

KTM as a teaching process attempts to activate a variety of learning styles and intelligences. For example, begin by explaining the lesson's goals (auditory stimuli), continue with a kinesthetic activity (kinesthetic and auditory stimuli), follow with a demonstration on the board (visual stimuli), enrich the experience by giving a kinesthetic activity for groups of students (kinesthetic, auditory and visual stimuli), facilitate a discussion while sitting in a circle (auditory stimuli), demonstrate on paper and ask students to demonstrate on paper while sitting in the circle (visual and auditory stimuli), and conclude with a kinesthetic activity (kinesthetic stimuli).

The cycle of auditory, visual, kinesthetic and tactile activities throughout the entire lesson ensures that all students are motivated and engaged all the time. All students "carry with them" all four learning styles, the issue is: which is their dominant learning style? Usually, students who are finding it difficulty to sit still for long periods of time, who are constantly in motion for one reason or another, are primarily tactile and or kinesthetic learners. Students who learn best from watching and looking are primarily visual learners. Students who learn best from listening are primarily auditory learners. Most of us are able to learn effectively in more than one way, which requires teachers to structure instructions to include activities that engage the auditory, visual, kinesthetic and tactile learning styles.

Finally, instruction is most effective if students are given the opportunity to link their own knowledge and experience to new information taught. Teachers should view themselves as facilitators of new information in the context of what students know and what makes sense in their lives. For example, instead of asking: "What is the right answer?", ask: "Given the information you just received, what could be one solution for this problem?" and: "Support your answer with your own life experiences". In taking this position, the teacher validates the students' experiences, creates extensions for new knowledge, and encourages the students to reason.

The use of music

Music affects one's mood, energy and motivation. Music determines the pace and in many respects affects the type of kinesthetic representations students would choose to perform. Music, by virtue of having its own speed and meter, will dictate how fast or slow the student will move in space. I recommend using instrumental music, which is unique in that it does not feature words. Instead, instrumental music stands alone as a musical piece by virtue of having a melody, an internal meter and speed. Instrumental music can be created by either music instruments or voice and should not feature words of any known language. Because of its reliance on the quality of the instruments, it is ideal for purposes of accompanying KTM instruction.

If you choose to incorporate music and build on that medium for teaching KTM, you will need to also teach your students about notes, pitch, rhythm, meter and beat. Teaching of these concepts should only be done when the lesson you are teaching requires the students to understand these terms. A teacher may choose to teach the term pitch when exploring the shape bank. A teacher could explain, for example, that a pitch can be very high (then demonstrate a shape that is very high off the ground), or very low (then demonstrate a shape that is very low and close to the ground).

Some teachers choose not to work with music. Instead they clap a steady meter to indicate the length of the dance students are suppose to dance, or the length of practice time. Practice time is over when the teacher either stops clapping or stops the music from playing.

Implementation taboos

Whether you are a teacher or a parent who would like to incorporate kinesthetic activities in your daily teaching activities, make sure that you do not make the following mistakes that could be counter-productive.

First, never force all students to find one common movement to represent a concept! For example, if you are teaching the alphabet letter "O", it should not be executed by all students raising their hands over their heads, creating a round ball shape. Just as a written repetition of an arbitrary letter shape does not help many students remember the shape of that letter, an arbitrary and dictated choice of movement to represent a letter will be similarly useless. In order for the kinesthetic process to be effective, each child needs to be given the freedom to decide what movements and body parts represent each letter or concept, and to find a meaningful explanation to connect the two.

Second, the teacher must make sure the choices students make are meaningful to them by asking them to share the reasoning behind their choices. If the emotional aspect attached to the word or letter is weak, often the learner may not be able to regenerate the shapes or sequences. If, after dancing several times the letter or sequence of letters, a student is not able to recall the shapes of letters and their sequence in a word, the teacher should assume that meaningful connections were not made. The learner should then be asked to draw on other experiences that are powerful and repeat the process with new movements.

Third, do not allow a student to use different representations for the same alphabet letter. The goal in using kinesthetic memory is to have the brain associate one kinesthetic shape with one letter. Having two or more body moves for one letter could lead to confusion and frustration.

Fourth, do not assume responsibility for remembering each student's word associations, written symbols of transitions, shapes or sequence of kinesthetic representations.

At the beginning of the process, it should be made clear to the students that they are responsible for finding ways to remember their own work. The teacher must remind them that they can be more successful in this process if they record their kinesthetic movements on paper, by drawing body shapes or sketching arrows to indicate direction of movements (their progression in space), elevation (how high the movement is off the floor) or fluency (whether the movement has any sudden stops and is performed with ease).

Frequently asked questions

Throughout my career I have come across many questions regarding the implementation and role KTM serves in learning and teaching. The following section shares these questions and provides clarification.

Must kinesthetic learners always move in order to memorize information?

Kinesthetic learners do not always have to move in order to remember information. If meaningful connections were created while implementing KTM, the learner would have developed a unique neurological connection that can be used in the future without actually moving in space. The learner will only need to imagine his or her body's movement in space, which triggers recall of the desired information.

How often should KTM be facilitated?

KTM should be facilitated daily and in each curriculum area, not instead of, but rather as a "fertilizer" of regular instruction. When KTM is applied correctly, other instructional approaches become more successful because the brain is able to apply knowledge that is developed in one area to be transferred to other areas. In cases where implementation of KTM begins at the upper grades of elementary or middle school, it should be used daily until curriculum goals are achieved, the foundation created is wide enough that less movement and more audio and visual modeling can be used, and students develop a strong comfort level using KTM.

Could KTM be facilitated in regular classrooms?

Any space that is designated for learning can be used for KTM. This would include a regular classroom, a dance studio, a section of the cafeteria, a part of the lawn or even an abandoned hallway.

What grade levels would benefit the most from KTM?

Children as young as 3 years of age and as old as 17 can achieve the best academic results if KTM is implemented daily, and if they want to learn to use this strategy. Adults who already recognize that traditional instructional strategies don't help them to learn, would (in most cases) find KTM an effective approach for learning.

Are there differences in the responses to KTM between male and female students?

Elementary grade female students seem to be able to respond more quickly to KTM than males because the process involves a developed ability to follow directions, connect with feelings, emotions and imagination, and work via communicating with each other. However, a successful teacher can choose to place greater emphasis on visual associations, which would encourage males to express their high energies with energetic movements. This would result in more classroom participation and a greater level of interest from male students. It is interesting to observe that males tend to choose energetic and forceful movements while females tend to choose softer movements that cover less space. Both types of movements should be encouraged, with the exception of movements that might harm oneself or others.

What type of homework can be given when implementing KTM?

Homework using KTM should include repeating the same process as done in class, on the same curriculum and with the same information. In addition, KTM should be used to work on new information and as a method for enhancing homework. Specific exercises should also be given to strengthen particular motor and cognitive skills. Students should be reminded that repeated rehearsing of their kinesthetic representations along with their verbal reasoning is essential for a high academic success.

What kind of tests should be given to students taught with KTM?

Three types of tests should be administered when implementing KTM: written, auditory and kinesthetic. Written tests should be in large type face and could include tasks like "fill in the blanks", "choose the most correct answer from a selection" and "identify the incorrect from several given alternatives".

Auditory tests require the teacher to read the question aloud for students to answer aloud. Kinesthetic tests allow students to present their dance and explain how the movements express their answer to the given question.

When would it be best to administer these tests?

These tests should be administered at the beginning of instruction, during instruction and at the end of a unit.

Do kinesthetic tests require the teacher to understand the movement?

No, it is not the teacher's responsibility to interpret the meaning of each student's kinesthetic representation. This is the responsibility of the students, and it should be made clear that they must find words to describe what their kinesthetic representations mean. At the same time, teachers who can offer students feedback related to the accuracy of execution are better able to enhance the students' kinesthetic and emotional experience, which will lead to better academic achievement.

Do teachers need to be dancers or have dance experience to best facilitate KTM?

Teachers do not need to be dancers or have dance experience in order to facilitate KTM. Teachers only need to have the desire to work in this medium in order to be successful in using it. Since teachers are not asked to perform or dance at any point during instruction, there is no need for such previous training.

What type of training is necessary for a person to facilitate KTM successfully?

KTM training is offered world-wide in teacher training as part of university and local school courses as well as privately. Training is specific to a particular content area and grade level and is offered in the areas of mathematics, reading, writing, and teaching and working with learning disabled children. All training is offered by The Washington Center for Learning located in the United States.

Final thoughts

Strategies for helping dyslexic students have been developed during the 20th century. KTM is one such strategy that was found to help dyslexic students learn to spell correctly at grade level. As with all research, the next step for educators and education advocates is to find ways for this information to be widely disseminated among practicing teachers, parents and students.

It would be interesting for future research to look at whether kinesthetic stimuli as implemented via KTM affect short and long-term memory, and whether information gained after being taught in KTM can be transferred intuitively into other curricular areas.

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Part III

Neurocognitive studies of dance

8 Neural mechanisms for seeing dance

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Introduction

The art of dance involves body movement as a way of expression. There are several elements or strands in a dance performance worth considering before elaborating this chapter. First, a dance performance typically involves several elements, including, but not limited to, narrative, costumes, music, or lighting. These may vary among different dance styles, cultures and societies. However, there is a core element (that may vary extensively in its form) that is shared among all dance styles: the *movement*. Second, these movements are performed by an agent that often requires specific motor and mental training in order to execute these movements with precision and fluency: the *dancer*. Third, dance is the process or product of deliberately arranging these elements (movements, dancers, scenario, and music) in a way that appeals to the senses or emotions of the audience, and is thus strongly connected to an *aesthetic experience*. Finally, the aesthetic experience is often the result of participation by an *observer* in a performance setting. These four elements: movement, dancer, observer and aesthetic experience, are discussed in the present chapter in the context of cognitive neuroscience.

Specifically, this chapter focuses on several issues that concern dance and science. Here, we leave slightly aside the training and the execution components of a dance performance, and instead focus on the stage of a dance observation; that is, when it is being watched. Using neuroimaging techniques, we illustrate what might go on in the human mind and brain when we see movements, and in particular, when we watch dance. We also consider a key aspect of dance: the motor skills of the dancers. These extraordinary acquired abilities not only change the way dancers perform, but also the way they see. Finally, we focus on a property tightly connected to dance: the aesthetic property of a movement, and how the observer represents aesthetic experience. To conclude, we summarize how science and art can learn from each other and develop ways of successful interaction.

The core element of dance: The movement

Movement is a physical displacement in time and space of the location of a body, or body part. Humans possess an extraordinary motor system that allows us to use movement as a means of interaction with the environment and with other individuals. Through movements we express our emotions, intentions and many needs. Classical motor neuroscience has studied in detail the human motor system, and its anatomical and physiological properties are well known (Berthoz, 2002). Recently, cognitive neuroscience has further investigated how different brain regions of the motor system participate not only in the observable movement execution, but also in internal action processes, such as having the intention to move, planning a movement or a sequence of movements and finally, implementing this order by sending appropriate commands to the muscles and effectors (for a review see Jeannerod, 1997).

From the perspective taken in this chapter, we will not talk much about movements, but about actions. Action can be defined as a voluntary movement directed to a goal (Jeannerod, 1997). Moving our arm forward and backward might be just a *movement*, but if we move our arm forward in order to reach a cup of tea, this *reaching* gesture is not anymore a mere *movement*, but a *motor act*. This simple motor act might be part of a more complex *action plan* to achieve a final goal or intention, in this case, to drink tea. This goal can be a physical external stimulus or an internally generated intention or need. Similarly, actions can be oriented towards an object, so-called *transitive* actions, like grasping a cup of tea, or *intransitive* actions, like waving our hand to say hello. Dance, for example, is mostly composed of intransitive actions, as often there are no (physical) objects required to drive the movement. However, dance cannot be that easily classified, and each style or even performance might have its own action properties. The movements might be completely guided by the rhythm of the music, or, in some dance styles such as tango or swing, there is a person who initiates the movement, the leader, while the partner performs a complementary movement in response, the follower. Nevertheless, the concept of action as a voluntary goal-directed movement can be applied in most cases (see also Chapter 2 by Rosenbaum, this volume).

Human motor repertoire

The *Oxford English Dictionary* defines *repertoire* as "the body of pieces known or regularly performed by a performer or a company". The term is originally French, but it derives from the Latin *reperire*, which means "to find" or "to discover". Cognitive neuroscience has studied the very similar concept of *motor repertoire*. This can be defined as a summary or storage of all motor knowledge we have acquired during our life. The single piece or unit of this repertoire is called a *motor representation* or *action representation*. The concept of motor representation has evolved since William James

(1890/1983) suggested "an idea of movement" that will generate some motor act, and Bastian's (1880) proposition that every time we execute a movement we generate motor traces or "kinetic images" that will be used every time we do that same movement. Nowadays, a motor representation is understood as a dynamic unit that can be modified by experience. This representation will be the core of an assembly of relationships between different sensory and motoric components. An action representation will be designated by internal or mental content related to the intention to act, action goals, or the knowledge of either physical or more general consequences of a given action, to the covert neural operations that are supposed to occur before an action begins and the physical implementation of motor commands into the muscles (see also the cognitive architecture model presented in Chapter 1 by Schack, this volume). Therefore, an action will be the observable outcome of previous internal information processing stages (Jeannerod, 1997). Finally, the elements that compose action representations should not really be considered as independent components but as a network of different nodes where all are related at cognitive and neural levels (in Chapters 1 and 4 by Schack and Bläsing, this volume, these nodes are termed *basic action concepts*).

We would like to draw attention to two factors that constrain the content of the human motor repertoire: physical properties of the basic musculoskeletal system, and personal and individual motor history. The first factor constrains our body through the limited number of flexions and extensions that our joints and muscles allow us to perform – we can only bend our arms and legs to a certain degree, and certain movements will always remain physically impossible, even after training. Therefore, the number of movements that a human can perform are limited by the physical properties of his or her body. The second factor is related to motor learning. From the moment we are born, we learn new motor skills by moving around our environment and physically interacting with other humans and objects. Most of these acquired motor skills are *common movements* (walking, running, reaching and grasping objects, hand gestures, etc.). However, life allows us to become *motorically unique*, by shaping the content of our motor repertoire when acquiring *specific motor skills* through *a particular* motor training. Therefore, each individual motor repertoire will be composed of *common actions* (shared by a large part of the human population) and *specific* or *personal actions* (only shared by those individuals trained in the same actions). For example, an individual trained in classical ballet has a motor repertoire of all the common movements we all know, plus those specific to the acquired technique (the canon of classical ballet: *pirouette*, *pas de chat*, *arabesque*, etc.).

Action and perception: Two merged systems

During a live dance performance, there are two fundamental processes that occur in absolute synchrony: the dancer *acting* on the stage and the spectator *seeing* the movements. Although it is difficult to dissociate the dance from the dancer, in a very broad sense, dance performers and dance observers focus on the same element: the movement. This common space between someone *doing* and someone *seeing* has been the focus of study for philosophers, psychologists and neuroscientists.

For a long time, action and perception have been considered two independent processes in the human brain. The perceptual system is formed by the different components that secure the processing of sensory information. By contrast, the action system comprises those components that participate in the different stages of producing motor acts. Descartes emphasized the difference between action and perception in the *Traité de l'homme* (1980), using two different metaphors for describing the two processes. However, other groups of philosophers and academics such as Lotze, James or Munsterberg have underlined the concept of a continuum between action and perception, suggesting the idea of a shared content between motor and perceptual representations. The neuropsychologist, neurobiologist and Nobel laureate Roger W. Sperry had already suggested that one basic function of the perceptual system was to prepare the system to act (Sperry, 1952). Later Konorski (1967) proposed that when we perceive a movement, our brain automatically executes the corresponding voluntary movement. And more recently, Berger described the relationship between the perception of different body part movements and the innervations of the corresponding muscles (Berger, Carli, Hammersla, Karshmer, & Sanchez, 1979). Psychologists have also produced a large set of literature supporting common or shared mechanisms for action and perception as well as theoretical models. One example is the common coding model, which proposes that codes related to action and perception are shared in a common representational domain (Prinz, 1997). Finally, from an evolutionary perspective, the human brain will not be more than the result of evolutionary changes, and among them, the action perception cycle would have a fundamental role. Definitively, action influences perception and perception influences action (Gibson, 1979). However, although a level of significant interaction between both perception and action systems was accepted, there was a lack of understanding about how this could be implemented in the human mind, and, more importantly, in the human brain.

Mirror neurons: The link between action and perception

The key answer for a common action and perception mechanism was found by neurophysiology studies in the monkey brain. Giacomo Rizzolatti and his colleagues, working in a neurophysiology laboratory in Parma (Italy), described for the first time a set of neurons in the premotor cortex of the monkey brain that responded when the monkey was doing a simple action (grasping), but also when the monkey was watching the experimenter or another monkey perform that same action (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Neurons with similar properties were subsequently also found in the parietal cortex (Gallese et al., 1996; Rozzi, Ferrari, Bonini, Rizzolatti, & Fogassi, 2008). It was already known that these regions had motor properties and responded during action execution, however, it was a completely novel discovery to see how the same neuron also responded to visual presentation of the action. This meant that the same neuron can have both visual and motor properties, and can potentially code information related to executing an action and seeing the same action. Neurons were called *mirror neurons*, because they seemed to reflect the observed action like a mirror onto an action that we have in our motor repertoire.

Since then, a series of studies have been undertaken to describe in more detail the properties of mirror neurons. One of the most interesting properties of the mirror neurons is their congruency between visual and motor responses. Each neuron is principally "specialized" in participating in the execution of a determinate action. Physiological studies have described in the primate premotor cortex neurons that specifically participate in actions such as grasping, reaching or holding. The concept of congruent mirror neurons means that those neurons that are specialized in *grasping* are also engaged during *seeing* grasping. In premotor and parietal cortex, we can find neurons with different levels of congruency. There are high levels of congruency among neurons that participate in execution and observation of the same action, but also neurons with lower congruency levels that participate in execution of several actions and observation of other similar ones. These mirror neurons are the first direct evidence linking together perception and action mechanisms. Their localization in a set of regions classically regarded as motor areas, such as premotor cortex, and also in parietal regions, indicates the importance of our motor system for the observation of actions. However, although monkeys are our very close relatives, the existence of a similar system in the human brain still needed to be demonstrated.

The first evidence of mirror neurons in humans came from a study using transcranial magnetic stimulation (TMS, see Box 4.1 in Chapter 4 by Bläsing, this volume). Fadiga and colleagues found that muscle excitability patterns during observation of simple grasping movements were congruent with those found during execution of the same actions (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). This was the first step to suggest that a *mirror neuron-like* mechanism also existed in the human brain. While other studies using the same technique confirmed these results (Baldissera, Cavallari, Craighero, & Fadiga, 2001; Strafella & Paus, 2000), a different group of studies aimed to localize brain regions with mirror properties in the human brain. These studies suggest that there is a set of regions that consistently participate during *observation of an action* performed by another agent. Among these areas (shown in Figure 8.1; see also Box 9.1 in Chapter 9 by Cross), we find the ventral and dorsal premotor cortex (vPM, dPM), as well as several regions in the parietal cortex, such as the inferior parietal lobe (IPL), superior parietal lobe (SPL) and superior temporal sulcus (STS) (Decety et al., 1997; Grafton,

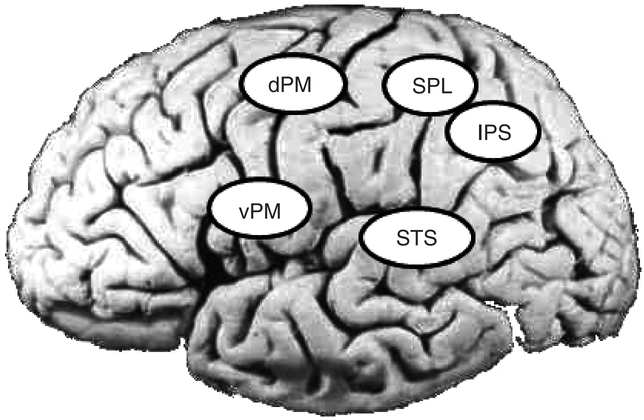

Figure 8.1 Schema of brain regions that participate in perception of movements. The marked areas are known to form part of the human mirror neuron system because they respond both during action execution and action observation. vPM; ventral premotor cortex, dPM; dorsal premotor cortex, SPL; superior parietal lobe, IPS; intraparietal sulcus, STS; superior temporal sulcus.

Arbib, Fadiga, & Rizzolatti, 1996; Grèzes & Decety, 2001; Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999; Rizzolatti, Fogassi, & Gallese, 2001). The supplementary motor area (SMA) and motor cortex are typically not activated, unless an element of movement preparation is also involved, for example in cases of action observation for delayed imitation (Grèzes & Decety, 2001). These areas are considered part of an *action observation network* that participates in several aspects related to action execution and observation (see Chapter 9 by Cross, this volume). *Motor simulation theory* takes these results into account and suggests that during action observation, there is automatic activation of high-order motor representations. However, initial TMS studies did show that there is a direct correspondence between observed and executed action (Fadiga et al., 1995), suggesting that brain processes for motor simulation are based on direct correspondence between the neural codes for action observation and for execution rather than a mere recovery of higher order abstract or multimodal action representations.

A later series of neuroimaging studies investigated the properties of the human mirror system, and how it responds to biological actions. First, these mirror regions were not activated during observation of mechanically impossible actions (Stevens, Fonlupt, Shiffrar, & Decety, 2000). Second, activation was stronger when humans saw actions performed by a biological agent rather than by an artificial one, a robot arm (Perani et al. 2001; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). Third, mirror regions seemed to follow a somatotopic organization during action observation similar to the one that can be observed during action execution (Buccino et al. 2001). This means observation of motor acts performed with different effectors, like the hand, mouth, or foot, leads to activation of specific parts of the premotor and parietal cortices that resemble the classical somatotopic organization described by Penfield in the motor cortex during action execution (Penfield & Rasmussen, 1950). Although some of these studies are controversial and follow-up studies have suggested alternative explanations (Gazzola, Rizzolatti, Wicker, & Keysers, 2007), overall they suggest that the human mirror system might be highly sensitive to the degree of correspondence between the observed action and the internal motor representation of the observer.

There are several issues that remain to be elucidated. First, most of these studies followed initial primate work on grasping execution and observation and used relatively simple and restricted sets of hand actions (Grafton et al., 1996; Rizzolatti et al., 1996; Grèzes & Decety, 2001). These studies reported brain responses during action observation, but have not directly tested whether observing a particular action involves activating our own motor programmes for that action. Buccino et al. (2004) performed an elegant study by comparing brain activation during observation of biological actions performed by another human or by a non-conspecific like a dog or monkey, and found that actions belonging to the motor repertoire of the observer showed stronger resonance in the mirror system regions. However, these activations did not fully account for the level of familiarity observers have with the acting agent, or the differences in kinematics between human and non-conspecific agents.

As we have described in previous sections, humans have a motor repertoire that far exceeds these simple hand–object-oriented actions. In this way, motor skills are a powerful tool to study the tuning of the mirror neuron mechanism. A particular action might exist in the motor repertoire of a trained expert, but not in the motor repertoire of someone who has not been so trained. We conducted a couple of studies that use this difference between people with different motor repertoires to test the assumption that watching an action simulates it internally in my internal motor system, with the specific motor pattern I use to perform the action myself. Therefore, internal simulation should be stronger if I know and can perform the observed motor act.

When mirror neuron theory meets dance

Neurophysiology studies in non-human primates and human neuroimaging studies have provided evidence that observing a simple movement activates the same neural regions used when we perform these movements ourselves. In order to directly test the hypothesis of a direct match between observed and executed actions, we have devised a novel paradigm that combines different levels of expertise (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). We studied groups of people with different acquired motor skills to investigate whether regions of the putative mirror neuron system are tuned to the individual's acquired motor repertoire. If this is true, the classical mirror neuron regions, such as premotor and parietal cortices, should exhibit stronger brain responses while watching actions that the observer has learnt to perform, compared to those that are novel or unfamiliar. However, a couple of important issues abut this approach are worth considering beforehand. First, one needs to find two separate groups of motor experts that differ in the specific acquired motor skills. Second, these different skills should be kinematically similar (with respect to speed, direction of movement, or involved effectors in whole body movements) in order to avoid obvious differences in visual processing of both types of actions.

Dance offers a great opportunity to realize these experimental affordances. Many dance styles (including classical styles such as ballet) involve arbitrary and intransitive movements of the whole body. Also, they are composed of a well established and distinct set of movements that can be easily classified: a vocabulary of movements (see Chapter 5 by Puttke, this volume). Each movement can be perfectly characterized by both its name and its dynamics. Therefore, professional dancers are the perfect motor experts for studying the influence of expertise on observing actions, as they have acquired the motor skills to perform a series of dance-specific movements in a highly coordinated way. Some dancers have been highly trained in only one dance discipline, acquiring its entire motor repertoire to perfection. Knowing the dance style a dancer has been trained in therefore allows us to characterize his or her motor repertoire. For example, a professional classical ballet dancer has acquired the motor representation of practically all defined canonical classical ballet movements.

Classical ballet and capoeira

We selected two types of dance disciplines that are comparable with respect to the kinematics of their movements, yet in which the movement shared little or no overlap with the movement of the other dance discipline. Classical ballet and capoeira are two dance styles that share this characteristic. With the assistance of dance choreographer Tom Sapsford we selected from all movements of the ballet and capoeira repertoire a list of those movements that matched according to criteria such as body parts used, direction of the movements, or movement speed. Most dance performances are more than a dancer performing a series of movements, and they are the results of the interaction of movements, music and costumes between others. However, in order to experimentally address the question of interest, we decomposed the dance into its core element and focused on the movements per se (for complementary studies that integrate other dance components such as motor execution and music see Brown, Martinez, & Parsons, 2006). Besides, in order to minimize the visual difference between the two sets of dance videos, performing ballet and capoeira dancers were morphologically similar and dressed in similar clothes.

Dancers in the scanner

We used functional magnetic resonance imaging (fMRI, see Box 4.1 in Chapter 4 by Bläsing, this volume) to measure brain activity of ballet and capoeira dancers watching video clips of 3 seconds each showing ballet and capoeira movements. At this stage of the experiment, both ballet dancers and capoeristas participated as mere observers, and they were required to lie still in the scanner room while watching the videos and performing an easy task to ensure that they were paying attention (i.e., after each video-clip, participants had to rate on a scale from 1 to 3 "how tiring" the movement appeared). The results showed that when we observe a dance movement that we have learnt before (e.g., ballet dancers seeing ballet movements), there are a set of neural regions that are more active than when one watches a kinematically similar movement that one has never performed before (e.g., ballet dancers seeing capoeira movements). Among these brain regions were the premotor cortex (ventral and dorsal sections), the superior parietal lobe and interior parietal sulcus in the parietal cortex, and the superior temporal sulcus in its posterior part. These regions belong to what previously has been described as the action representation system or action observation network (Decety et al., 1997; Grafton et al., 1996; Grèzes and Decety, 2001; see also Chapter 9 by Cross, this volume). These results suggest that when I observe a familiar action, I retrieve information related to that action by recruiting it from the action representation network. In this way, by observing a movement, one can access the information previously stored related to that movement. This includes motor information related to the specific motor commands to perform the action, sensory information, and semantic information associated with that action (e.g., movement name, memories related to that movement; see also Chapter 4 by Bläsing, this volume).

This study supports the idea that we perform an internal simulation when we observe an action and that this simulation is represented in the brain, evidenced here by stronger activity in regions involved in the action observation network. However, there is a question that remains unsolved. It refers to which component of the action representation network is retrieved during observation. More specifically, does action observation predominantly engage purely motoric mechanisms, over and above the visual representation of the action, semantic knowledge of the action, or its aesthetic experience? In order to answer this question, we needed to disentangle the different components of the action representation. After interactions with dancers and choreographers, we became aware of an important factor through which classical ballet movements are classified. In classical ballet there are gender-specific movements (i.e., movements that are mostly trained and performed by either male or female dancers, but not both), and gender-common movements (trained and performed by both genders). Therefore, female dancers trained in classical ballet will have acquired motor training of female-specific moves, and vice versa for male dancers. However, as female and male dancers train and perform together, both genders will acquire visual familiarity and semantic knowledge about all the movements, regardless of their gender specificity. We therefore conducted a subsequent experiment that allowed us to dissociate visual and motor familiarity, and to test for neural regions that are more responsive to an internal simulation of the action in motor terms, over and above any associated visual or semantic representations (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006).

The experiment again used an action observation task. Now female and male classical ballet dancers watched 3-second video clips of gender-specific dance movements. These movements were performed by a female dancer and a male dancer, dressed in black clothes. We also used a set of dance movements commonly performed by both genders, to rule out any possible effects related to observing a female or a male dancer. In order to dissociate purely motor and visual representations during observation of gender movements, it was essential that only classical ballet dancers trained specifically in their corresponding gender moves (and not in the opposite gender moves) participated in the study. We controlled dancers' motor training using a preliminary questionnaire enquiring about how often they do and see in their professional training the movements used in the experiment. This questionnaire showed that male dancers were visually familiar with both male and female movements, but only motorically familiar with the male ones, and the opposite for the female dancers. This control is particularly important nowadays where rules of classical dance are broken in order to create novel performances where male dancers perform ballet moves classically associated to females (for examples see Les Ballets Trockadero de Monte Carlo, http://www.trockadero.org, or Matthew Bourne's Swan Lake, http://www.swanlaketour.com).

The results of this study are very straightforward and conclusive. To summarize, we looked for brain activity changes related to gender, and gender-specific and common classical ballet movements, in order to find areas tuned by purely motor resonance with the observed action, rather than other action-related information such as visual or semantic knowledge. We found that brain activity was higher in three regions for observation of movements with a strong motor familiarity, compared to observation of movements with only visual familiarity. These areas are the premotor cortex in the left hemisphere, and the superior parietal lobe and cerebellum bilaterally (Figure 8.2). Because our experimental design controlled for visual familiarity and other information associated with the action, we could relate the activation in these areas to an internal motor resonance and our own motor system action codes. One can generalize and conclude that when we observe a familiar action that we have previously performed ourselves and therefore have motorically learnt, the human brain evokes an automatic

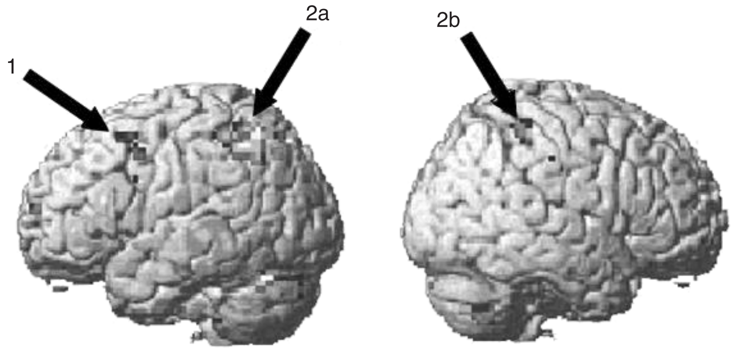

Figure 8.2 Effect of motor expertise on action observation. Activations shown represent the activation associated with seeing an action for which the observer possesses the motor representation. These areas are the core of the mirror system and seem to sustain a network for internal motor simulation during observation. (1) left dorsal premotor cortex, (2a) left intraparietal sulcus, and (2b) right intraparietal sulcus (modified from Calvo-Merino et al., 2006).

response and employs a code for motor execution that enables *seeing* the action. We seem to code external motor events through our own motor repertoire.

In general, these series of studies combining acquired motor skills, such as dance, and action observation paradigms may provide some useful insight not only for the cognitive neuroscience community, but also for the dance community. On the one hand – *message to the action observation community* – these studies show for the first time neural responses to action observation of whole-body intransitive actions, and how this activity is modulated by the observer's motor experience. On the other hand – *message to the dance community* – these studies illustrate how dancers are specialists not only in the way they *move* thanks to their motor training, but in the way they *see* other people's movements. These studies and similar ones using dancers' expertise (Cross, Hamilton, & Grafton, 2006; Chapters 4, 9 and 10 by Bläsing, Cross and Jola in this volume) illustrate that the motor knowledge and training that dancers have acquired during their career are shaping the way their mind and brain process information related to movements beyond the mere motor execution, such as simple observation of dance movements.

Aesthetic perception of dance

The term *aesthetic* derives from the Greek word *aesthesis* and was redefined by Baumgarten in the 18th century as the gratification of the senses or sensuous delights (Goldman, 2001). The term *aesthetic experience* is defined as a particular psychological state elicited by a type of sensory stimulus that is, often, but not exclusively, a work of art. Philosophy, psychology and several other disciplines have produced a large number of essays and studies on aesthetic experience. Among them, two classical perspectives have led researchers to focus mainly on two elements of aesthetics: the perceived stimuli and the observer. Most aesthetics studies have used artwork such as music or static stimuli like paintings, and very little work has been done in other art disciplines. Dance is one of the performing arts that uses the dynamics of the human movement as a form of expression, and often associates it with an aesthetic value. Here we revisit some of the classical aesthetics theories from psychology and new studies developed from neuroscience in the newly named discipline of neuroaesthetics. Finally, we focus on a special way of seeing actions: the aesthetic perception of dance.

The psychology and neuroscience of aesthetics processing

The psychology of aesthetics has produced two main theories that focus on different components associated with the concept of evaluation: *objective* theory and *subjective* theory. *Objective theory* focuses on the intrinsic properties of the evaluated object ("this is a beautiful item"), while the second theory focuses on the subjective experience or attitude of the observer ("I like it"). Objectivist theories emerged from early psychophysical studies that focused on identifying particular stimulus properties or arrangements of attributes that induced aesthetic experience, such as symmetry, balance, complexity, and order of stimuli. One such example is the *golden cut* that will induce an aesthetic feeling in any observer and will be preferred to any other composition of stimuli (Livio, 2002). These studies have used a wide range of stimuli, from simple geometrical figures to more complex stimuli such as paintings (McManus, 1980; McManus & Weatherby, 1997; Jacobsen, 2004; Jacobsen, Buchta, Kohler, & Schroger, 2004; Jacobsen & Hofel, 2002). A common finding is that aesthetic experience depends on compositional arrangements between parts of the stimulus, and between individual parts and the whole, and that all observers share a common perceptual mechanism for seeing these attributes (Leder, Belke, Oeberst, & Augustin, 2004). In conclusion, the objectivist theories suggest that the perceptual system of an observer will treat beauty and other aesthetic properties of our environment like any other attribute of it. On the other hand, subjective theories support the common saying "beauty lies in the eye of the beholder". This perspective completely counters the objectivist viewpoint by giving larger importance to individuals' preferences, taste and attitudes. In this way, each individual is special and unique, and his or her preference should be the product of interaction between idiosyncratic factors such as personal experience and cultural environment (Zajonc, 1968). Psychology has tried to create models that unify individuals' behaviour, but the subjectivity of aesthetic behaviour has increased the difficulty of this task, and only one model has been developed to integrate psychological states in a neuropsychological model of aesthetics (Chatterjee, 2004).

Yet, with the advance of neuroscience and modern neuroimaging techniques such as fMRI and magnetoencephalography (MEG, see Box 4.1 in Chapter 4 by Bläsing, this volume), a new discipline, called neuroaesthetics, has emerged. It focuses on investigating the neural mechanisms underlying the internal processes associated with aesthetic experience, such as aesthetic evaluation, aesthetic judgement, and aesthetic perception (Cela-Conde et al., 2004; Kawabata & Zeki, 2004; Vartanian & Goel, 2004). In general, most early studies in neuroaesthetics aimed to describe the brain mechanisms involved in aesthetic evaluation per se, regardless of the physical properties of the preferred item. These studies recorded brain activity while participants explicitly evaluated the aesthetic properties of static images such as paintings, objects, casual scenes or geometrical figures (Cela-Conde et al., 2004; Kawabata & Zeki, 2004; Jacobsen, Schubotz, Hofel, & Cramon, 2006; Vartanian & Goel, 2004). As often in the early stages of a new discipline, there has been little consensus on the concepts, predictions, or methodologies required for studying neuroaesthetics, which has produced a mix of both converging and divergent results (for a review see Nadal, Munar, Capo, Rossello, & Cela-Conde, 2008). Nevertheless, overall the current literature suggests that the neural mechanism of aesthetic processing (and more particular, aesthetic evaluation) might be distributed along at least three types of networks or processes. These are a perceptual, a cognitive, and an emotional mechanism.

The first mechanism refers to an early sensory or perceptual component. It is through these components that a piece of art or stimulus reaches the human mind. The mechanisms underlying audition and vision are well studied in the scientific literature. For example, a network of visual cortical areas independently processes multiple features of visual stimuli, such as colour, form, motion and depth independently (Zeki & Lamb, 1994). Several recent studies have reported more brain activity in visual areas during the perception of stimuli that were going to be aesthetically evaluated (Jacobsen et al., 2006; Kawabata & Zeki, 2004; Vartanian & Goel, 2004). Among these regions, extrastriate areas (Jacobsen et al., 2006) and the occipital and fusiform gyri (Vartanian & Goel, 2004) are repeatedly reported as active when subjects see stimuli that they like, as opposed to dislike. Similar regions show responses while evaluating different degrees of attractiveness of faces (Iidaka et al., 2002; Paradiso et al., 1999). Although it is still unclear whether these activations are related to preference or merely show functional specialized processing and perception of the category of stimuli being judged (Moutoussis & Zeki 2002; Zeki, Watson, Lueck, Friston, Kennard, & Frackowiak, 1991), it is widely accepted that "all visual art must obey the laws of the visual system" (Zeki & Lamb, 1994).

A second cognitive or semantic component can be defined as part of the aesthetic processing. Several neuroaesthetics studies have shown activity in areas related to cognitive processes such as memory or social cognition during positive evaluation of beauty. Cela-Conde and collaborators, for example, have shown stronger activity in the prefrontal dorsolateral cortex when participants were watching and evaluating their preference for different paintings (Cela-Conde et al., 2004). This region has also been described as the centre of the perception–action interface and is critical for the monitoring and comparison of multiple events in working memory (Cela-Conde et al., 2004; Petrides, 2000). Activity in another frontal region, the fronto-median cortex, jointly with activity in prefrontal regions, as well as temporal-parietal brain areas, has been found in another study that compared brain responses during aesthetic judgements and perceptual judgements, like symmetry (Jacobsen et al., 2006). Interestingly, these same sets of regions are involved while performing other judgements about human nature, such as social and moral judgements (Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003). Overall, this might indicate that aesthetic processing involves the combination of specific mechanisms for aesthetic evaluation, as well as those common to general judgements.

Finally, we can describe a hedonic or emotional component associated with the reward of the stimuli regardless of their aesthetic properties. This assumption is supported by studies showing brain responses in the orbitofrontal region of the prefrontal cortex during the observation of stimuli rated as beautiful compared to less liked ones (Kawabata & Zeki, 2004; Kirk, Skov, Christensen, & Nygaard, 2009). There are no studies comparing the temporal dynamics of the cognitive and hedonic components during aesthetic response, however, it is likely that cognitive processing and hedonic or reward mechanisms work in parallel during the perception of sensory stimuli, linking systems for individual preference behaviour, and basic pleasure and emotion. The previously described aesthetic components clearly suggest that seeing beauty involves at least three separate stages or mechanisms, including perceptual processing, cognitive processes related to memories, and emotional processes associated with reward. Neuroaesthetics is a new field, and some of the neural activations described here are not fully consistent across studies; however, this might be because of the use of different paradigms rather than the lack of specific neural processing for the aesthetic response. Overall, it can be concluded that a dedicated set of regions participate in the explicit aesthetic evaluation of beauty, although the role of each component and the stage of its participation in the general aesthetic response is still to be determined.

Other important aspects to consider are the following. First, previous studies have mainly focused on subjective approaches and have compared different sets of stimuli according to individual preferences, allowing for a general view of the brain responses of the observer during the aesthetic evaluation process. However, they have given little attention to the physical properties of the selected stimuli. This provides little information about which physical properties of stimuli are responsible for the aesthetic experience of a participant. Second, most of these studies have used paintings as the art form to be aesthetically rated, and although some new research has been done on ancient sculptures (Di Dio, Macaluso, & Rizzolatti, 2007) and architecture (Kirk et al., 2009), there is a blank space waiting to be filled by dynamic artistic expressions such as dance. Therefore, after evaluating the state of the art, we propose a new approach for studying neuroaesthetics.

First, and most importantly, it complements the studies that focus on static stimuli such as paintings (Cela-Conde et al., 2004; Kawabata & Zeki, 2004; Vartanian & Goel, 2004) or music (Blood & Zatorre, 2001), by focusing on a specific dynamic stimulus from the performing art never studied before: dance. Second, we move away from the classical explicit evaluation of beauty to study implicit processing embedded in the automatic perception of stimuli. And last, we use a consensus approach, which, compared to the individual and subjective approach, allows us to identify brain responses for an average observer. This last issue is particularly important because it allows us to project the results from the activated brain regions back into stimulus space and describe physical properties of the dance movements that have an associated neural response.

Neural correlates of implicit aesthetic responses to watching dance

The way we perceive the external world is modulated by intrinsic factors such as our current mood or previous experience. Aesthetic processing is similarly affected by these factors. Kant (McFarland, 1970) stated that observers need to be in a certain state to have an aesthetic experience. Therefore, every time we walk into an art gallery or a performance theatre, we prepare our senses for an aesthetic experience. Neuroimaging studies have tried to grasp the essence of this specific *mood for aesthetics*, also called *aesthetic attitude* (Cupchik and László, 1992), by evoking this attitude under laboratory conditions, while measuring brain activity that may correlate with this process. Later, different neural responses for positive judgements ("I like this image") were compared to negative ones ("I do not like it"). However, one would expect that there is more to aesthetic experience than the explicit judgement of beauty. Otherwise no spontaneous aesthetic pleasure could arise unless we were in the appropriate mood.

We prepared a study whose aim was mainly twofold. First, we aimed to investigate neural responses that correlated with implicit aesthetic experience, extending previous work on aesthetics of static stimuli to the performing arts, in this case, dance (a complete description of this study can be found in Calvo-Merino, Jola, Glaser, & Haggard, 2008). Second, we aimed to analyse the data so that we could look back into stimulus space, and identify the stimuli that produced the strongest aesthetic responses, both at a subjective level and at a neural level. We divided the study into two sessions. In the first session, we measured brain responses in naive participants with no formal dance experience while they watched dance movements and performed a dummy task (to ensure they paid attention to the stimuli). It is important to note that no explicit aesthetic question was asked during the viewing inside the brain scanner. As in previous studies, we worked closely with a choreographer in order to select a range of dance movements from different cultural backgrounds (classical ballet and capoeira). Combining responses for both dance disciplines allowed us to evaluate general responses to dance perception, irrespective of dance style. The selected movements were classified on the bases of four kinematic properties: speed, used body part, direction of movement, and vertical and horizontal displacement. This pre-classification is important to later produce a physical description of the movements that elicited different aesthetic responses. In a separate second session, participants were shown the same dance videos and were asked to rate them individually in an aesthetics questionnaire that contemplated five dimensions (Berlyne, 1974). These were liked–disliked, simple–complex, interesting–dull, tense–relaxed and weak–powerful. From this questionnaire, the only dimension that showed significant levels of correlation with neural activity was liked–disliked. We therefore focused on this dimension during the analysis and discussion.

We analysed brain activity using standard procedures (for a full description, see Calvo-Merino et al., 2008). The subjective ratings for each movement were first normalized within each subject and then averaged across subjects to create a *consensus* rating of the group of participants for each movement. We then divided the movements into two subsets: one group contained the top half movements with the highest scores (more liking), the other those with the lowest scores (more disliking). We then used this group average of all subjects' ratings to identify brain areas sensitive to whether they were watching a generally high or low rating in this aesthetic dimension, as determined by the consensus scores. We found two specific brain regions showing significant neuroaesthetic tuning. These regions were more activated when subjects viewed movements that, on average (in the consensus), they liked, compared to movements that, on average, they disliked. These aesthetics-sensitive areas are localized in the early visual cortex, in the medial region, and in the premotor cortex of the right hemisphere. These areas therefore may be relevant for implicit positive aesthetic experience of dance (see Figure 8.3). No significant results were found for the opposite comparison; that is, when looking for brain regions sensitive to viewing less preferred rather than preferred movements. This result suggests that an automatic sensorimotor response underlying our current mechanism for seeing actions (or dance in particular) is sensitive to implicit positive aesthetic feeling. Similar activation in the premotor cortex has been found in the previously described studies during action observation. Therefore, the results from the present aesthetics study are in agreement with previous statements that underlined the relation between the perceptual mechanism for perceiving the stimuli and aesthetics processing (Zeki & Lamb, 1994).

Back to the movement

The subjective approach has been widely used in most previous neuroaesthetics studies, where brain analysis has often been driven by individual responses

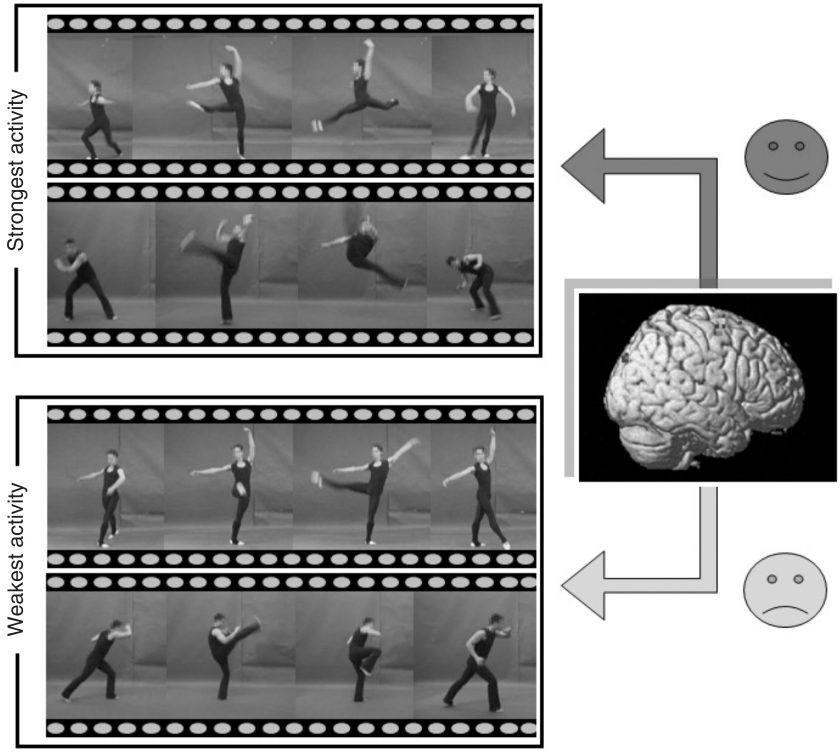

Figure 8.3 Sensorimotor aesthetic tuning during observation of dance movements. The right panel illustrates brain areas whose responses correlate with the group consensus aesthetic evaluation of dance movements on a scale between "like" and "dislike". These are premotor cortex in the right hemisphere and visual cortex bilaterally. The images on the left panel show footages of the dance movements (3 seconds) that activate strongly and weakly the premotor and visual brain regions. Note that the movements in the top box (stronger activation) include horizontal and vertical displacement (jumping), while those in the bottom box (weaker activity) involve mainly one limb and little displacement (modified from Calvo-Merino et al., 2008).

and aesthetics ratings. This approach allows for identifying brain areas that participate in aesthetics decisions, but it does not allow for making any inferences about the stimuli that evoke this response. The consensus approach that we have presented here (for details see Calvo-Merino et al., 2008) does not allow generalizing the result to the general population, as we eliminated differences between individuals when generating the consensus average. However, it does allow us to identify individual stimuli that specifically modulate the aesthetics-related brain areas described in the group of subjects that participated in this study. Because movements were selected on the basics of four criteria, we can now produce a physical description of those dance movements that preferentially target these aesthetics-sensitive areas. We then identified which specific dance movements were responsible for maximal and minimal activation for the two aesthetically responsive brain areas (visual and premotor cortices). Figure 8.3 shows an example of the movements that achieve highest and lowest neural responses for the occipital area in the left hemisphere and the equivalent stimuli for right premotor activation. This result suggested that, on average, these aesthetics-sensitive areas preferred whole body movements, such as in jumping in place or with a significant displacement of the entire body in space, like horizontal jumps. When we performed the same type of analysis based only on the behavioural data, we observed that the kinematic properties of the movements that received highest and lowest consensus liking score in the subjective rating showed clear correspondence with the moves that target the brain areas revealed as aesthetically relevant in the functional imaging analysis. These two latest results suggest a correlation between subjective liking and neural liking. It is of course impossible to determine (within the setting of the present experiment) which process precedes which. Does a strong sensorimotor resonance produce a stronger feeling of beauty in movements? Or does the way we feel beauty modulate the level of sensorimotor response? Or is positive aesthetic feeling the result of the perfect interaction of both subjective and neural responses? These questions raise the possibility of continuing research on the neuroaesthetics of performing arts, using a sensorimotor framework.

Conversations between neuroscience and dance

Scientific research as well as dance production are processes that involve several stages and different people with different abilities and responsibilities. For example, a dance performance requires at least the participation of choreographers, dancers, and an audience to observe the final product. During our research, we have mainly focused on dance perception rather than the creative process of dance or dance execution. In particular, we studied how neurocognitive mechanisms involved in observing dance movements are sensitive to different factors, such as the observer's experience with the observed movement and implicit aesthetic experience. However, despite focusing on the dance observer, during some stages of the research process there was an inestimable contribution of the dance execution section of the performance team, that was comparable to the one needed in a dance performance setting. Our experience told us that in order to create an efficient communication between artist and scientist and avoid a Babel tower, there is a need to embrace the different views of each world (art and science) and synthesize a common language. Once this is done, ideas can flow and fertilize the other approach and knowledge for a common matter of interest: in this case, dance. Although every collaboration is unique and can develop in its own way, our experience has shown us two pathways. The first is to involve full collaboration and interaction between scientist and artist along the entire path of a study. This helps to address questions of common interest, leading to a common and shared output. While this may be a desired and ideal scenario, in reality it is often difficult to pursue (see also Chapter 10 by Jola, this volume). The second path is mostly unilateral, and can work for both scientists and artists. From the scientist's perspective we have here reported a series of studies that use dance or dancers as model participants, in order to address specific experimentally driven questions – this can include dance itself (Brown et al., 2006; Calvo-Merino et al., 2005, 2006; Cross et al., 2006; see also Chapters 4, 9 and 10 by Bläsing, Cross and Jola, this volume). In this type of interaction, the artist–scientist collaboration might be necessary only at some stage of the research, even if it is a key factor. In our own studies, it was the experimenters' role to define stimulus requirements to test the experimental hypotheses (kinematics properties, length, colours, etc.). We then discussed this information and the aim of the study with an experienced choreographer, who, being familiar with our experimental framework and approach, made a final selection of movements appropriate for the experiment, and guided the dancers while performing the steps in the video recording session. Although this collaboration was essential for the success of the research, as well as the participation of professional dancers as subjects, this collaboration was limited to the early stages of the research timeline, and was developed ad hoc to fit into the original experimental hypothesis. From the artist's perspective, there is the possibility of benefiting from science as a source of inspiration for choreographing new movements or whole performances (for an example see Wayne McGregor, AtaXia, 2004, http://www.choreocog.net/ataxia.html). However, this side of the collaboration is better discussed by other writers with intrinsic knowledge of the dance world (deLahunta & Barnard, 2005; Hagendoorn, 2004; Jola, Chapter 10, this volume).

Another issue to consider in science–art collaborations regards the different methods that both disciplines use to pursue their final aim. Only after this has been understood, can one start talking and sharing work in progress and outputs. While the researcher and the artist aim either to generate support for a theory, to find out whether a hypothesis regarding a specific phenomenon is correct, or to produce a final work of art, they pursue the same target from different ends. Basically, the differences are a result of different views on two extremes, the whole and the part. The approach of science is to understand a phenomenon (here: a dance performance) by performing an analytical decomposition of its parts or elements. Then, each component is investigated in isolation. This initial segmentation is essential to study independent contributions of each specific component and their participation in individual processes (see Chapter 4 by Bläsing, this volume). Artists, on the other hand, manipulate parts and units to compose the whole. For example, in order to create a dance performance, one has to combine individual elements such as movements, as well as take care of the performing dancers, scenario and costume (as described in Chapter 6 by Zöllig, this volume). All these merge together in perfect harmony to create the dance performance we see from the other side of the dance theatre.

Considering this last point, the logical question to ask is: Can the artist collect the information about the individual elements that science can provide and put them back together into a piece of art? The studies presented here have illustrated the human neural mechanisms that participate in the observation of movements in general, and dance movements in particular. In order to conduct this research and isolate the elements of interest, we reduced dance movements to their minimal expression, by using short video clips and minimizing variability between dancers' bodies and costumes. This allowed us to identify a neural network that participates during the observation of dance. This network could be the basis of an internal motor simulation mechanism that matches the actions we watch with internal action representations stored in our own motor repertoire. More importantly, we also showed that this sensorimotor mechanism is sensitive to the nature of familiarity – visual or motor – that the observer has with an action (Calvo-Merino et al., 2005, 2006) and to the level of implicit liking during mere observation in non-familiar observers (Calvo-Merino et al., 2008). Interestingly, because we previously described the physical properties of individual movements, each video clip can be conceived as an independent movement unit whose properties are known. Besides, we know what level of preferences each of these movement units elicits in the sensorimotor network of the observer. Therefore, it would be interesting to see how choreographers collect these movement units, and develop a performance or choreography *à la carte* that stimulates specific brain regions required for an aesthetic experience. Thinking ahead, and imagining that research following this approach will increase over the years, one can start to imagine how it may be to create a performance that effectively stimulates different components of the aesthetics processing network.

Here we propose a new tool, namely the use of knowledge about the neural mechanisms underlying action observation in an observer. Taking into account the properties of the system that is going to perceive and probably judge the final production, the brain, might help to control the quality or quantity of an observer's experience. It is difficult to distinguish the piece of art from the observer (for a 2009 example see Antony Gormley's Fourth Plinth Commission for Trafalgar Square, London, entitled "One and other", http://www.oneandother.co.uk). And even if researchers have used theories and methods of cognitive science to describe aspects of dance, such as choreographic thoughts and creativity (Stevens and McKechnie, 2005), only time will tell how cognitive psychology and neuroscience knowledge about the way humans see dance and feel pleasure will influence the way dance is produced, or how much these disciplines will be considered by the choreographer in the artistic creation process.

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9 Building a dance in the human brain

Insights from expert and novice dancers

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As humans, we have an unparalleled ability to coordinate our bodies to perform an endless number of skilled actions. As dancers, this ability is even more impressive, as a dancer's motor repertoire comprises movements that are not only highly skilled, but also remarkably precise, complex, and coordinated. An intriguing feature of the human brain is how a network of seemingly disparate cortical regions and subcortical nuclei can give rise to dance movements, from the razor-sharp precision of 32 *fouettés en tournant* performed by Odile in *Swan Lake* to the contorted, convulsive, and seemingly out-of-control whole-body flings and gyrations that typify the choreographic vocabulary of Twyla Tharp's *Torelli*. Of particular interest to neuroscientists is the remarkable plasticity of the human brain to integrate different types of physical and perceptual experiences to learn new movements. Such abilities are quite pronounced in dancers, whose livelihood depends on rapid and adept movement production and reproduction. How does the brain accomplish this feat? Neuroscientists have recently observed that it is the extraordinary plasticity of seemingly disparate cortical regions and subcortical nuclei within the brain that gives rise to such movements. This network of brain regions works together when we observe someone else performing an action and then learn how to perform it ourselves.

Neuroscientists first found evidence of a neural system that matches action with perception in the brains of non-human primates (see also Chapter 8 by Calvo-Merino, this volume). Scientists stumbled on this finding almost by accident, when they were recording from single neurons within the ventral premotor cortex (area F5) of the monkey brain to determine how these neurons responded when monkeys grasped different items. These researchers observed, much to their surprise, that the same neurons that fired when monkeys performed a specific action (e.g., grasping a raisin) also fired when the monkey watched another monkey or a researcher execute the same action (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996a). Subsequent research revealed that these particular neurons do indeed respond preferentially to actions that are either observed or performed, which led researchers to name them "mirror" neurons. As such, mirror neurons appear to compose a cortical network that matches observation of actions with execution of those same actions (Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Rizzolatti et al., 1996b). These specialized neurons have prompted researchers to propose that action perception and production processes form a bidirectional, interactive loop within the primate brain.

Since the discovery of mirror neurons in monkeys, many studies have investigated similar functional regions within the human brain, providing evidence for a human mirror neuron system (e.g., Rizzolatti & Craighero, 2004), or, more broadly, an *action observation network* (AON; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009b). For the purposes of this chapter, the term *action observation network* is used instead of *mirror neuron system*, since this term is more general and encompasses all of the brain regions involved in action observation processes, not simply the two main mirror neuron regions (inferior parietal and premotor cortices). As illustrated in Figure 9.1 (see also Box 9.1), the brain regions that compose the AON include the supplementary motor area (SMA), the ventral premotor cortex (vPM), the inferior parietal lobule (IPL), and posterior superior temporal sulcus/middle temporal gyrus (pSTS/pMTG; Binkofski et al., 2000; Decety, 1996; Grafton et al., 1996; Rizzolatti et al., 1996b; Stephan et al., 1995). Increasing evidence from behavioral, neuroimaging, and neurostimulation procedures suggests that action understanding might be explained by covert simulation of another's movements by an observer (Decety, 1996; Fadiga, Buccino, Craighero, Fogassi, Gallese, & Pavesi, 1999; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Jeannerod, 2001; Rizzolatti & Craighero, 2004).

The challenge for research on the relationship between action perception and action production is to determine the explanatory power and generalization of this network and its relationship to motor skill and new action learning. It is the hope of researchers in this field to eventually explore applications for the recovery of function after injury and improved learning and teaching practices. The focus of this chapter is on work my colleagues and I have performed on the neural and behavioral outcomes of humans learning to perform complex action sequences, specifically dance. First, I introduce work we have performed with expert dancers that probed questions of the neural representation of whole-body action expertise. Next I discuss findings from a study performed with novice dancers through which we addressed questions of observational learning and how learning is influenced by different action cues. I conclude with a brief discussion of the broader implications for this work and suggest several directions for future research.

My colleagues and I have turned to populations of expert and novice dancers to help us address such questions of action cognition for several reasons. Dance requires a great degree of coordination not only between the different limbs of the body, but also between perception and action, and time and space. As an example, most dancers can relate to the experience of

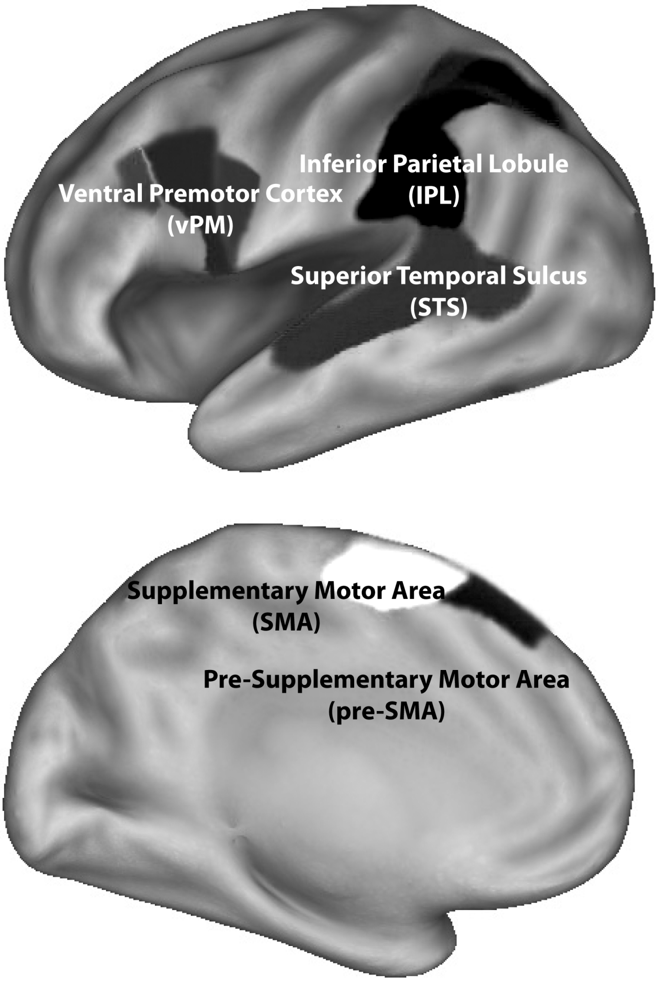

Figure 9.1 Cartoon representation of the action observation network (AON). The core regions that compose the AON are rendered here on partially inflated cortical surfaces using the PALS data set and Caret visualization tools (http://brainmap.wustl.edu/caret). The brain illustrations throughout this chapter appear different from the brains illustrated by Calvo-Merino (Chapter 8, this volume), because the Caret tools render brains to appear slightly inflated, which enables better visualization of activations deep within sulci and on the cortical surface. The AON is represented bilaterally, but for visualization purposes, the medial and lateral surfaces of the left hemisphere only are illustrated here. The AON includes the ventral premotor cortex (vPM), the inferior parietal lobule (IPL), the superior temporal sulcus (STS), and the supplementary and pre-supplementary motor areas (SMA and pre-SMA).

Box 9.1	**Brain areas involved in action observation processes**
SMA:	supplementary motor area
vPM:	ventral premotor cortex
dPM:	dorsal premotor cortex
IPL:	inferior parietal lobule
SPL:	superior parietal lobe
IPS:	intraparietal sulcus
pSTS:	posterior superior temporal sulcus
pMTG:	posterior middle temporal gyrus
ITG:	inferior temporal gyrus
pSTG:	posterior superior temporal gyrus

showing up to a technique class in a new studio, progressing with ease through the warm up or *barre* exercises, and then being expected to perfectly perform long and complex sequences of steps that have been rapidly demonstrated in the most cursory manner (see also Chapter 5 by Puttke, this volume). Dancers' ability to transform scant visual or verbal information into highly sophisticated movements has great potential value to scientists. Significant utility exists in examining both beginning and expert dancers to see how complex movements are learnt, remembered, and reproduced. Not only can scientists learn about the coordination and expression of complex actions by quantifying dancers' behavioral performance, but careful measurement of how such skilled actions are represented at the neural level can shed additional light on how the human body is capable of learning and performing such complex movements with limited information.

Placing the dancer's brain in a scientific context

In line with research from our laboratory, which has studied *de novo* dance learning in both expert and novice dancers, elegant work by several other laboratories has substantiated the feasibility of using dance learning and observation as a paradigm for investigating the properties of the AON (Brown, Martinez, & Parsons, 2006; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Calvo-Merino, Jola, Glaser, & Haggard, 2008; Calvo-Merino, Chapter 8, this volume; Jola, Chapter 10, this volume). The first such study investigated the specificity of the AON for observing one's own movement repertory compared to an unfamiliar and untrained movement repertory (Calvo-Merino et al., 2005; see also Chapter 8 by Calvo-Merino in the current volume). In this experiment, expert ballet dancers, capoeira dancers, and non-dancer control participants passively viewed ballet and capoeira dance clips while undergoing fMRI scanning (see Box 4.1 in Chapter 4 by Bläsing, this volume). The authors reported significantly greater activity within the AON, including bilateral vPM and IPL activity, right superior parietal lobe, and left STS, when dancers observed the movement style of their expertise. From this, the authors concluded that the AON is able to integrate one's own movement repertoire with observed actions of others, thus facilitating action understanding.

A second influential study by Calvo-Merino and colleagues (2006) examined the effects of visual compared to motor experience on AON activity during action observation. In order to parse visual familiarity from physical experience, expert men and women ballet dancers observed videos of movements learnt only by their sex, only by the opposite sex, or moves that are performed by all dancers (see Chapter 8 by Calvo-Merino, this volume). The motivation behind this procedure was to determine whether equally robust action resonance processes may be elicited by observation of movements that are equally visually familiar, because men and women dancers train together, but are unequal in terms of physical experience. The authors reported that when effects of visual familiarity are controlled for (i.e., when dancers watched moves from their own movement repertoire, compared to moves that they frequently saw, but never physically performed), evidence for action resonance based on pure motor experience was found in inferior parietal, premotor, and cerebellar cortices. The authors conclude that actual physical experience is a necessary prerequisite for robust activation in these areas of the AON. This study provides an excellent point of departure for one of the lines of research described below, wherein my colleagues and I were interested in measuring how purely observational experience is represented in the AON.

Together, the studies led by Calvo-Merino et al. (2005, 2006) and Brown et al. (2006) provide robust evidence for changes within the AON with the presence (or emergence) of execution competency. My colleagues and I have aimed to build on this foundation by addressing open questions regarding the establishment of motor and perceptual expertise, the sensitivity of this network to physical and observational learning, and how learning from another dancer's movements compared to just symbolic cues influences learning and neural activity. The studies discussed below address these three objectives through training experiments performed with expert and novice dancers. By tackling such questions about the function of the AON through use of both behavioral and neuroimaging measures in dancers, we aim to better characterize the processes that underlie the various ways people acquire new movements.

What expert dancers' brains can teach us

The first study our laboratory performed with dancers aimed to address three objectives (Cross, Hamilton, & Grafton, 2006). First, we sought to characterize how the human brain represents expertise for complex, whole-body actions (in this case, dance sequences). The second objective was to determine whether the neural signature for newly learnt complex dance sequences differs from kinematically similar sequences that are unlearnt. Finally, we wanted to determine if neural activity was related to individuals' perceived mastery of the dance movements that they learnt. We hoped that by tackling these questions, we might add a measure of clarity to a continuing debate in the study of action simulation concerning the relationship between the physical embodiment of actions (i.e., those actions that an individual can perform and has performed) and neural activity when observing such actions.

In this experiment, participants were asked to observe a dancer's movements and at the same time to imagine themselves performing those movements. In this situation, the visual stimulus guides and constrains the motor simulation. Because our task involved action observation as well, it is essential to consider how visual stimuli depicting human actions are able to drive motor regions of the brain. As mentioned previously, numerous neuroimaging studies implicate the motor and premotor areas that are classically associated with movement preparation as also being engaged when simply observing the actions of others (Buccino et al., 2001; Grafton et al., 1996; Grèzes & Decety, 2001; Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999; Johnson-Frey, Maloof, Newman-Norlund, Farrer, Inati, & Grafton, 2003; Rizzolatti et al., 1996b). Behavioral studies have further demonstrated interactions between action perception and execution (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Brass, Bekkering, & Prinz, 2001; Hamilton, Wolpert, & Frith, 2004; Kilner, Paulignan, & Blakemore, 2003), and thus lend additional credence to the idea of overlapping neural processes for action observation and execution. A meta-analysis of 26 functional neuroimaging studies on action representations by Grèzes and Decety (2001) provides evidence that extensive overlap exists between brain regions active during action observation, simulation, and execution. Together, these findings suggest that a distinct set of brain regions compose the AON, and are active both when observing and when performing actions.

In our study, we recruited 10 expert modern dancers who were learning the movement vocabulary from Laura Dean's seminal modern dance work, *Skylight* (Dean, 1982). The dancers spent over 5 hours per week learning the *Skylight* vocabulary as part of their company's repertory. Importantly, this was a longitudinal study in which the dancers' brains were scanned once a week across 6 weeks of learning this new dance work. Such a method enabled us to effectively take snapshots of the expert dancers' brains as they progressed from unfamiliarity with the new movement vocabulary to an expert level of performance proficiency. During the weekly scanning sessions, the dancers watched 18 video clips of *Skylight* movements, and 18 videos of kinematically similar but unfamiliar and unrehearsed dance movements. The dancer in the video clips was filmed from behind as she moved in front of a mirror. This not only enabled our participants to see nearly 360° of visual information about the movements, but it also provided an ecologically valid viewing context, since dancers are accustomed to observing and practicing movements in front of a mirror in a studio context. While the participants watched each video clip in the scanner, they were asked to imagine themselves performing each dance sequence. Following each video, a question appeared asking the dancers to rate their perceived performance ability for each sequence, at that particular point in time.

The behavioral and neuroimaging procedures yielded several exciting results about the representation of expertise in dancers' brains. Unsurprisingly, we found that the dancers rated their ability to perform the rehearsed *Skylight* movements as progressively greater across the 6 weeks of training, while their ratings of their ability to perform the control movements remained relatively unchanged (Cross et al., 2006). The neuroimaging results corroborated and extended previous work on expert dancers in several capacities. First, in line with what was reported by Calvo-Merino and colleagues (2005), we saw greater activation across a broadly defined AON, including parietal, premotor, supplementary motor, and superior temporal regions, when dancers watched dance movements compared to rest, and when they watched movements they had physically rehearsed compared to unrehearsed control movements (Figure 9.2, top two brains). The critical contribution of this study was that as the dancers' expertise with the rehearsed dance sequences increased, activity within vPM and IPL in the left hemisphere also increased with their perceived expertise (Figure 9.2, lower brain).

This study provided evidence for rapid and precise changes in AON responses within the brains of expert dancers learning a new dance. In just 6 weeks, dancers progressed from novices to experts with the *Skylight* choreography (as evidenced by their subjective evaluations of performance ability). While watching the movements they were most expert at performing, greater neural responses were observed in the left premotor cortex and the left inferior parietal lobule. These two regions have been found to contain mirror neurons in monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti et al., 1996a), and form the crux of the mirror neuron system in humans (Rizzolatti & Craighero, 2004). By studying dancers who were in the midst of intensive rehearsals to learn a new work, we were optimally poised to discover what goes on in the brain as individuals build movement expertise from the ground up. However, one major shortcoming of this study is that the dancers were not scanned prior to beginning rehearsals for *Skylight*. Thus, while we were able to take snapshots of their brains across the rehearsal process, we did not have a clear measure of how the AON responded to rehearsed movements before they were ever seen in the studio. With our next study, we attempted to overcome this issue, as well as the limitation of using subjective performance ratings, through investigation of novice dancers learning simple dance sequences.

What we can learn from the novice dancer's brain

While research with expert dancers has shed light on the neural correlates of highly skilled action embodiment (e.g., Calvo-Merino et al., 2005; Cross

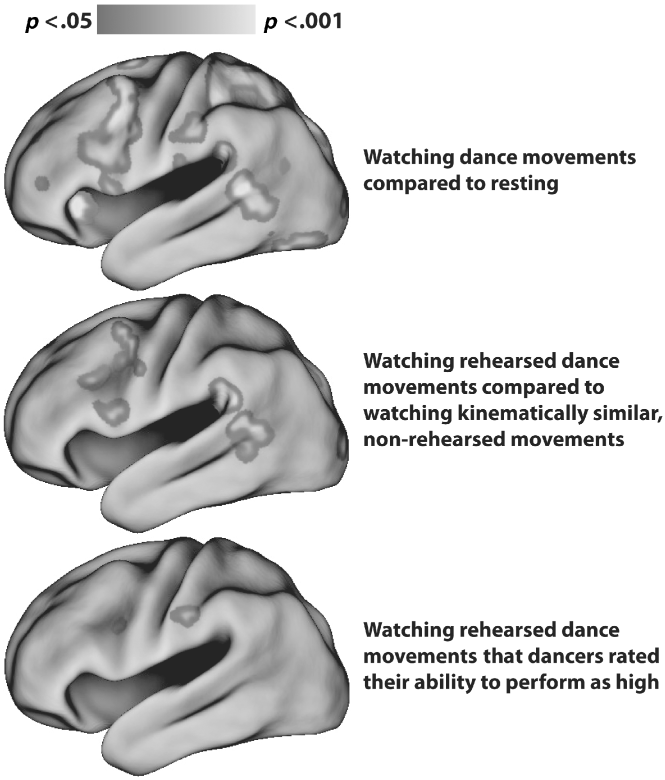

Figure 9.2 Results from functional imaging study with expert dancers. A selection of results (only the lateral surface of the left hemisphere) from three brain imaging contrasts from the Cross, Hamilton, and Grafton (2006) study on action expertise among expert dancers.

et al., 2006; Bläsing, Chapter 4, this volume), a look into the brains of novice dancers who are learning to integrate visual and auditory cues with coordinated whole-body movements can be equally instructive for our understanding of complex action learning. We know that many avenues exist for learning new dance movements. To return to the dance class example introduced earlier, if an instructor wants her students to perform a particular combination of steps, she could accomplish this in a number of different ways. She could verbally name or describe the sequence of individual steps, she could indicate or gesture the movements with her hands, she could show her students a string of symbols that denotes the combination in Laban movement notation (see Box 5.1 in Chapter 5 by Puttke, this volume), or she could perform the desired sequence herself.

To parse how different methods of learning might influence performance, this study focused on novice dancers. Here, we controlled how novice dancers learnt new dance movements and examined resulting changes in each novice dancer's AON. We measured dance performance accuracy and neural activity within a group of participants who had no previous dance experience or training as they learnt simple dance sequences in an interactive video game context. In order to address our experimental objectives, we used a three-by-two factorial experimental design (Figure 9.3, panel A). We explored two separate, but related, avenues of new action learning in novice dancers: observational learning and learning from human versus symbolic action cues. This study was carried out over 8 consecutive days, as illustrated in Figure 9.3,

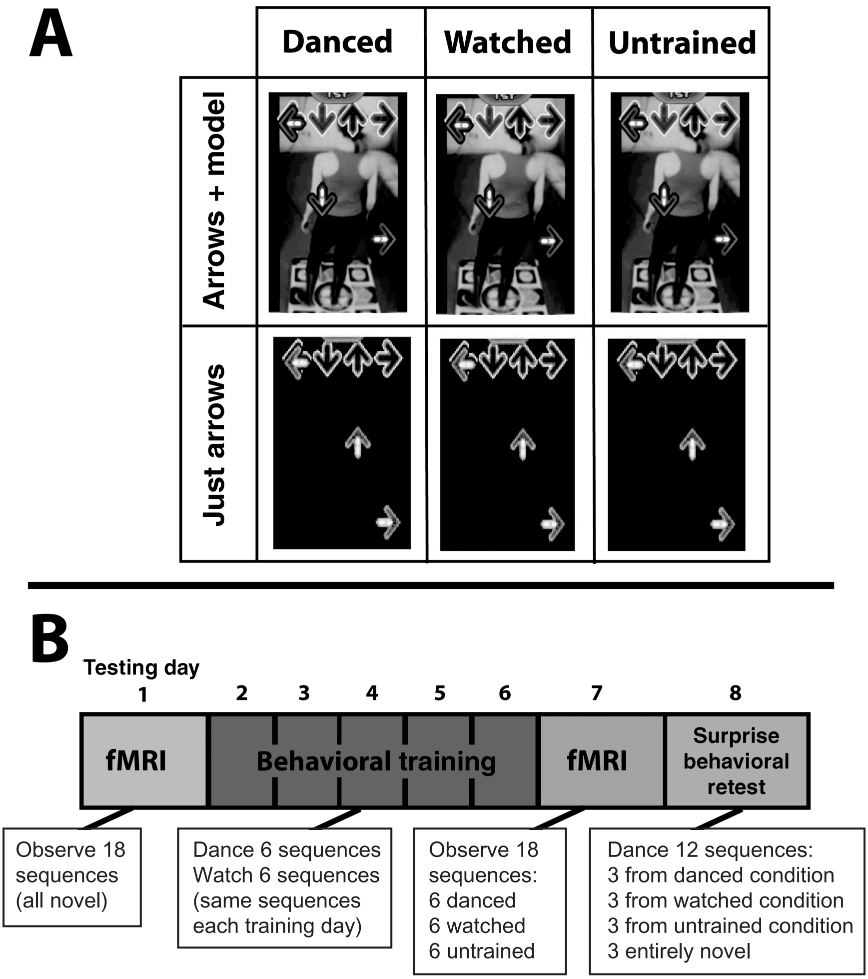

Figure 9.3 Experimental design and time course for experiments with novice dancers. Panel A represents the 3 (training experience: danced, watched, or untrained) by 2 (action cue: dancer with arrows or just arrows) study design. Panel B depicts the 4 phases of the study in chronological order.

panel B. Our first objective was to determine how observational learning, such as when one simply watches a dance instructor without imitating the movements, and then tries to reproduce the movements at a later point in time, is represented within the AON (Cross et al., 2009b). The second objective was to determine how movement training influences activity within the AON – both while observing an expert model accurately performing the actions (such as when one dances in step with a dance instructor while observing her movements) and when relying on purely symbolic cues (such as when one follows a diagram or symbolic notation of step patterns; Cross, Hamilton, Kraemer, Kelley, & Grafton, 2009a). Even though both questions were investigated with a single study, for the sake of clarity, each objective is considered in turn.

Learning from observation

When we learn to walk, use a fork, or drive a car, we learn by first observing others do the task, and then practicing it ourselves. It is thus unsurprising that a wealth of behavioral research suggests that the quickest and most accurate learning results from observing and simultaneously reproducing another individual's movements (e.g., Badets, Blandin, & Shea, 2006; Bandura, 1977, 1986; Blandin, Lhuisset, & Proteau, 1999; Blandin & Proteau, 2000; Schmidt, 1975; Sheffield, 1961). This research has demonstrated that not only is observation helpful for learning (Blandin et al., 1999), but that physical practice is more beneficial than mere observation of new movements (Badets et al., 2006). One aim of our study with novice dancers was directed at further exploring the separate and combined contributions of these factors on acquiring novel movement sequences. Additionally, using functional neuroimaging, we aimed to characterize the neural underpinnings of observational learning with or without the added benefit of physical practice.

Early behavioral investigations by Sheffield (1961) led to the proposal that observation of a model provided a "perceptual blueprint", or a standard of reference for how the task to be learnt should be performed. Carroll and Bandura subsequently proposed that this perceptual blueprint improves learning by providing a means for the detection and correction of performance errors as well (Carroll & Bandura, 1987, 1990). Behavioral studies comparing observational and physical learning support the idea that observational learning in conjunction with physical practice can bolster learning over physical learning alone (Blandin & Proteau, 2000; Carroll & Bandura, 1990; Doody, Bird, & Ross, 1985; Lee, White, & Carnahan, 1990; Zelaznik & Spring, 1976; for a review, see Hodges, Williams, Hayes, & Breslin, 2007). In one such study, Blandin and Proteau (2000) asked participants to perform a task that involved performing a precise arm movement while avoiding obstacles. Participants physically rehearsed without observing a model perform the action, observed a novice performing the task before attempting to perform the task themselves, or observed an expert performing the task before attempting it themselves. Observation of either type of model enabled participants to develop error detection and correction skills as effectively as physical practice. This led Blandin and Proteau to conclude that individuals can develop error detection and correction as effectively from observational learning as they do from physical learning.

One of the primary theories why observational and physical learning have so much overlap is that they both engage similar cognitive processes (Barzouka, Bergeles, & Hatziharistos, 2007; Blandin et al., 1999; Bouquet, Gaurier, Shipley, Toussaint, & Blandin, 2007). For instance, a recent psychophysical and electromyographic (EMG; see Box 4.1 in Chapter 4 by Bläsing, this volume) study demonstrated that participants' learning of a novel, complex motor task is facilitated if they previously observed another individual learning to perform that same task, compared with watching another individual perform the task without learning, or learning to perform an unrelated task (Mattar & Gribble, 2005). However, as Blandin and colleagues note (1999), such findings do not mean that physical and observational learning are *identical* cognitive processes; particular features are unique to each kind of learning.

Such behavioral research establishes a solid foundation for exploring areas of overlap and divergence between observational and physical learning. However, it is difficult to determine with only behavioral experimentation the degree of correspondence of cognitive processes subserving these two types of learning. Behavioral and EMG studies alone cannot satisfactorily address the underlying neural mechanisms. Here we benefit from using functional neuroimaging, which can identify the neural mechanisms engaged during observational and physical learning. If both types of learning engage the same areas of the brain, then we can infer that both observational and physical learning engage comparable cognitive processes. Conversely, the emergence of different areas of neural activity based on learning would imply that distinct cognitive processes underlie these two types of learning.

We investigated observational learning by training novice dancers to perform complex dance movement sequences while manipulating training elements. Specifically, we sought to determine whether observational and physical learning result in quantitatively similar or different behavioral performance and patterns of neural activity. Because of the complexity and unfeasibility of having participants physically perform dance sequences in the scanner (but see Brown et al., 2006 for an innovative approach to this problem involving tango dancing in a PET scanner), we instead chose to train participants to perform the movement sequences with music videos outside the scanner, and then asked them to observe the training videos during the scanning sessions. The focus of this portion of the study was on differences between the three training conditions; danced, watched, and untrained (Figure 9.3A, B).

Seventeen young adult participants who had no dance training and no experience with playing dance video games first came into the laboratory to participate in an fMRI session while they watched and listened to 18 upbeat music videos. Half of these videos featured a person dancing along with arrows that scrolled upwards on the screen, and the other half had only the arrows scrolling on the screen. This first scanning session was followed by 5 consecutive days of dance training, where participants spent approximately 1 hour in the laboratory each day, practicing dancing six music videos (henceforth to be referred to as the "danced" condition), and resting while passively viewing, but not dancing, another set of six music videos (henceforth to be referred to as the "watched" condition).

We used StepMania software (www.stepmania.com), in conjunction with a dance pad connected via a USB to a desktop computer, to display the dance videos and record participants' dance performance. StepMania is a freeware version of the popular video game "Dance Dance Revolution" (Konami Digital Entertainment, Inc., Redwood City, CA). We chose to use an interactive video game in order to precisely quantify dance performance, instead of relying on subjective ratings, as we did in the Cross et al. (2006) study, while also maintaining participants' attention and interest across the lengthy training procedures.

Following 5 days of dance training, participants returned for a second fMRI session, where they observed the same 18 music videos from the first week of scanning. This time, however, six of those videos were highly familiar from having been physically practiced, another six videos were visually familiar from having been passively viewed during each training day, and the remaining videos had not been seen since the first week of scanning. In contrast to the instructions given to our expert dance participants in the study discussed above (Cross et al., 2006), participants in this study were instructed to simply observe the videos. Following the second scanning session, participants returned to the lab to perform a surprise dance re-test of a selection of the dance sequences they had practiced dancing, a selection of dance sequences they had passively observed, and a selection of untrained and entirely novel dance sequences.

Behavioral findings indicate that participants' performance of the sequences from the "danced" condition significantly improved across training days. Moreover, results from the surprise behavioral re-test show that participants were able to perform the dance sequences they passively observed during the week of training at an intermediate level between those sequences they danced and the untrained and novel sequences.

The imaging analyses were designed to accomplish three objectives. The first objective was to determine which brain regions were active when participants observed the dance music videos before ever stepping foot into the training room. This was achieved by identifying regions that showed a greater response while observing all music videos (task) compared to watching a static black screen with a white fixation cross in silence (baseline) from the pre-training scanning session. This contrast revealed broad activation within the action observation network. This pattern of activity was used as a mask for the next two imaging analyses from the post-training scanning session, in order to limit the search volume for the effects of interest. The next analysis identified neural regions that showed distinct response profiles when observing videos that were danced or watched. Here we found evidence that physical practice engages select components of the AON above and beyond passive observation. Specifically, participants recruited heightened activity in the right precentral gyrus when presented with videos they had danced, and did not recruit this same area when viewing videos they had only passively viewed during training. This pattern of findings is consistent with the notion that physical practice engages select components of the AON above and beyond passive observation (Aglioti, Cesari, Romani, & Urgesi, 2008; Calvo-Merino et al., 2006).

This is not to suggest that observational learning relies on an entirely different system than physical learning. Indeed, a conjunction analysis revealed that both physical and observational learning engaged activity in select areas of the AON (Figure 9.4). Further statistical analyses (detailed in Cross et al., 2009b) indicated that the neural responses within these two regions did not differentiate between videos that were danced or watched, but responded more strongly to videos that had been trained in either of these manners compared to videos that were untrained and observed only during scanning. When considered together, the imaging analyses from this study suggest that, at least among our sample of novice dancers, physical and observational learning share more commonalities than differences at a neural level.

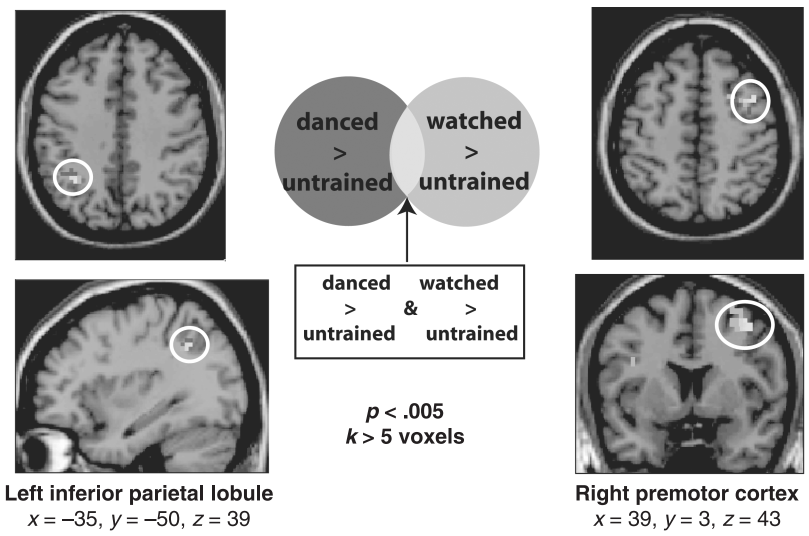

Figure 9.4 Brain regions that respond to physical and observational learning in novice dancers. Two regions of particular interest that demonstrated similar patterns of activity when novice dancers watched dance videos they had trained on throughout the week, or merely passively observed, are illustrated here on a rendered cortical surface of a standard brain from the Montreal Neurological Institute (MNI).

The converging evidence from our behavioral and neural measures serves to link the rich history of behavioral research on observational learning with the burgeoning field of neuroimaging inquiry into action cognition. We found it especially remarkable that such clear evidence emerged for observational learning in light of the fact that participants were never explicitly told to try to learn the sequences they watched each training day. Evidence from other studies suggests that the amount of observational learning we reported in this study could have been markedly increased if we had explicitly instructed participants to try to learn the sequences they watched during the training procedures (e.g., Hodges et al., 2007; Mattar & Gribble, 2005).

These results are generally in agreement with findings from the extant literature on dance representations in the brain (e.g., Cross et al., 2006; Calvo-Merino et al., 2005; Brown et al., 2006), which suggest that that AON, particularly parietal and premotor components of this network, is modulated by experience. The present investigation makes several novel contributions to this literature through inclusion of two critical control conditions, namely, the use of an "untrained" experimental condition in addition to the danced and watched conditions, and the inclusion of a pre-training scanning session. The inclusion of the pre-training scan is an especially valuable contribution, as it enabled us to quantify the effects of the dance training manipulation with greater precision than we were able to do in the Cross et al. (2006) study.

Of course, these findings are not without their limitations. The most serious limitation stems from our use of a within-subjects experimental design. A valid criticism of this design is that observational learning does not occur in a purely observational context, since all of our novice dance participants were also learning to dance particular sequences during the same sessions that they passively observed different sequences. However, we believe that our results are not invalidated by this criticism, as evidenced by dance performance scores and neural responses to stimuli from the untrained experimental condition. Put simply, if the skills participants were learning in the danced condition transferred uniformly to other conditions, then we would have expected a lot less differentiation between the watched and untrained conditions, which we did not see. Overall, what this portion of our study with novice dancers demonstrated is that several cortical regions of the AON respond in a similar manner to observational and physical learning. At present, a great need exists for future research to explore the different parameters that might influence observational learning at a brain and behavioral level, including motivation to learn, which part of the model provides the most information for learning a new skill, and how different kinds of instructions might influence observational learning.

Learning from other dancers versus learning from symbols

Another feature of action cognition that we examined with the same novice dancers was the specificity of the action observation network to learning from other humans, compared to learning from abstract symbols. In the past, several different functions have been proposed for the AON, including action prediction (Kilner, Friston, & Frith, 2007; Prinz, 1997, 2006; Schütz-Bosbach & Prinz, 2007), action understanding (Rizzolatti & Fadiga, 1998; Rizzolatti et al., 1996b; Rizzolatti, Fogassi, & Gallese, 2001), inferring the intention of others (Fogassi, Ferrari, Gesierich, Rozzi, Chersi, & Rizzolatti, 2005; Hamilton & Grafton, 2006; Kilner, Marchant, & Frith, 2006), and social cognition (Iacoboni & Dapretto, 2006). Previous imaging studies of this network have not directly compared these functions within the same experiments to determine whether different components of this network might serve specific, individual functions. One particularly unsettled issue is whether or not this network responds exclusively or even preferentially to observation of actions performed by other humans. For example, one could imagine that it is simpler to learn how to dance the *Macarena* from watching another person perform it than by following stick figure depictions or a computer simulation of the movements. One factor that can help determine whether the AON responds to the actions cued by other humans, per se, is whether it responds when actions are cued symbolically, or only to observation of another person performing the action. Moreover, if the AON has a specific role in action prediction and action understanding, then manipulating the degree to which an action can be easily understood should also affect the level of activity in the AON. One way this can be evaluated is by varying the amount of direct experience one has in performing an observed action. To accomplish this, we used the same novel dance training paradigm introduced above to determine whether activity within the AON is driven by action embodiment or by the form of the action stimuli.

If the AON is dedicated to action understanding, we might expect it to show a preference for biological motion stimuli, as some recent data suggest (e.g., Kessler et al., 2006; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004, Brass et al., 2000). Brass and colleagues (2000) were among the first to report that participants were measurably faster to imitate finger movements that were performed by another person compared to those that were cued by a spatial cue. Kessler et al. (2006) performed a follow-up study to Brass et al.'s (2000) to more fully investigate why this was the case. Using whole-head magnetoencephalography (MEG), Kessler and colleagues monitored participants' brain activity while they performed a finger tapping movement cued by a video of a finger tapping (biological movement condition) compared to a dot over the digit to move in a still photograph of a hand (non-biological movement condition). They report that left premotor and bilateral parietal and superior temporal cortices were more active during the biological than the non-biological movement condition. Further, they posited that these regions are probably working together (along with several other subcortical regions) to confer the behavioral advantage of faster reaction times when imitating biological movements compared to symbolically cued movements. Tai and colleagues report converging findings when individuals watched grasping performed by a human compared to grasping performed by a robot model controlled by an experimenter (Tai et al., 2004). They observed greater activity within the left premotor cortex when participants watched a human actor than when watching a robot model, which led them to conclude that the AON is specifically tuned to observation of biological movements.

The notion that the AON responds preferentially to human compared to non-biological action cues remains controversial. Several other studies have shown that this network will respond to non-biological stimuli in a similar way as to biological stimuli (Gazzola, Rizzolatti, Wicker, & Keysers, 2007; Press, Bird, Flach, & Heyes, 2005). In one such study, Gazzola and colleagues monitored participants' neural activity with fMRI while they observed either a human hand or a robotic hand perform simple and complex actions (Gazzola et al., 2007). They observed robust activation across several regions of the AON, including dorsal and ventral components of the premotor cortex, superior parietal lobule, and the middle temporal gyrus when participants observed a human or robotic hand perform an action, compared to a static control image. Moreover, activation was greater when humans or robots were performing more complex, goal-oriented actions that were familiar to participants, such as grasping a cocktail glass, compared to simpler and possibly less relevant or familiar actions, like moving wooden blocks around. The authors interpret these findings as consistent with the notion that observation of familiar actions, or familiar action goals, will reliably and robustly activate the AON, regardless of the lack of correspondence between the acting agent and the observer (Gazzola et al., 2007).

The inferences that can be drawn from the study by Gazzola and colleagues (2007), and indeed, similar studies (e.g., Brass et al., 2000; Kessler et al., 2006; Press et al., 2005; Tai et al., 2004), are critically limited by participants' dissimilar amounts of experience or familiarity with the human and non-human action cues they observe within the task. For example, participants in these previous studies were most likely very familiar with observing hands grasping objects in every day life, but were probably less likely to come across robots grasping objects or abstract symbols cuing actions in their daily lives. With our study, we avoided confounding biological motion with familiarity through the use of intensive training procedures. Using this innovative approach, participants were taught to perform novel dance sequences with both biological and symbolic action cues (Figure 9.3A). Such a methodology enables a precise control of participants' familiarity and physical experience with the action stimuli they observe while being scanned. This permitted a measure of brain responses during action observation where biological motion could be studied independently from experience.

The objective of this portion of the study was to clarify the contributions of several key components of the AON to observation of action cues both with and without a human agent. Specifically, we tested whether the AON is driven by observation of other humans, or whether it is driven by observation of familiar or executable actions. We directly manipulated both the presence of a human dancer and participants' physical experience with the dance sequences. If the action observation network responds uniformly as a function of observing humans or experiencing, then we would expect stronger responses across all components of the AON when observing biological motion compared to non-biological motion (e.g., Kessler et al., 2006; Tai et al., 2004), and when observing trained compared to untrained sequences (e.g., Calvo-Merino et al., 2005; Cross et al., 2006). However, if it is the case that individual components of the AON are sensitive to different kinds of experience, we would predict that distinct components of this system should respond differently based on experience and the presence of a biological agent.

The experimental procedures were identical to those described above for the observational learning portion of the study. One critical feature of the training stimuli that merits restating is that for all categories of stimuli (danced, watched, and untrained), half of the videos featured an expert human model dancing the sequences along with the arrows, and half of the videos had only the arrows denoting the sequences without a human model. Interestingly, when we reanalyzed the behavioral performance data across the five days of dance training, a small but significant effect emerged of the presence of a human model. Participants' dance scores were marginally higher for sequences that included a human dancing along with the arrows (Cross et al., 2009a).

The imaging analyses for this objective pursued two aims: to determine the effects of the presence of a model on AON responses, and to determine the effects of training. The three-by-two factorial design (Figure 9.3A) was essentially distilled to a two-by-two factorial design for this portion of the study, with training (trained versus untrained) and presence of human (human present versus human absent) as the two factors of interest. Functional imaging data from the post-training scanning session revealed a strong activation within bilateral posterior temporal cortices when participants observed videos that had a human model present (Figure 9.5, top). A robust main effect of training was observed in the right ventral premotor cortex (Figure 9.5, bottom), suggesting that this area was sensitive to the effects of training regardless of the training stimulus. However, bilateral posterior temporal cortices were uniquely sensitive to training stimulus.

Taken together, this pattern of results indicates that some parts of the AON respond preferentially to physical experience (ventral premotor cortex) while other parts respond specifically to the presence of a human model (posterior temporal cortex). The finding that ventral premotor cortex (vPM) responds most strongly to cues for actions that have been physically experienced and not to the presence of a human model, advances our understanding of what this region contributes to action cognition. Since the discovery of mirror neurons in an analogous region of monkey premotor cortex (area F5) (Gallese et al., 1996; Rizzolatti et al., 1996a), several hypotheses have been

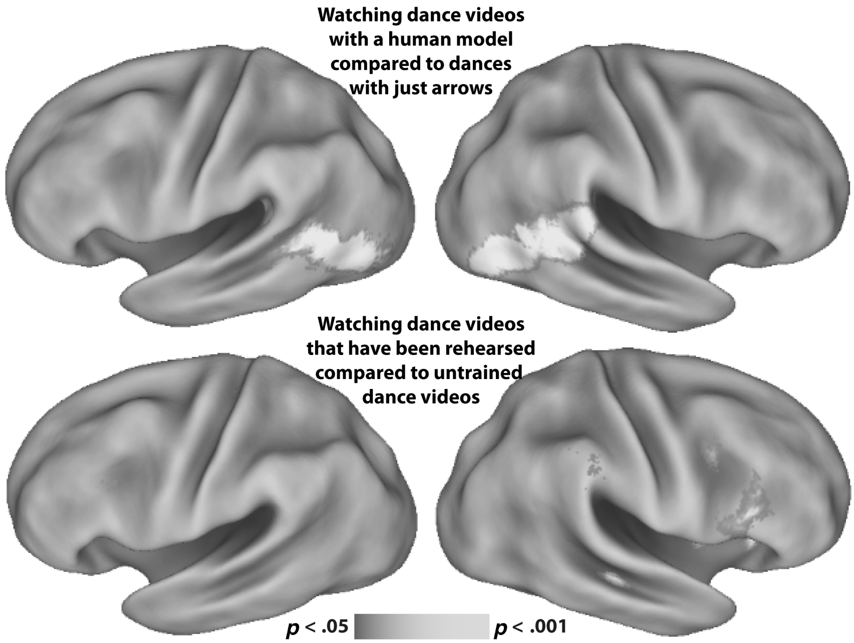

Figure 9.5 Brain regions that respond to training and the presence of a dancer in novice dancers. The top two brains illustrate brain regions that respond to the presence of a dancer on the screen, independent of novice dancer participants' training experience with the videos. The bottom two brains illustrate brain regions that respond to dance videos that the novice dancers have trained to dance, independent of the presence or absence of a dancer on the screen.

put forward for the role of premotor cortex in motor and social cognition, including predicting the ongoing actions of others (Kilner et al., 2007; Prinz, 1997, 2006; Schütz-Bosbach & Prinz, 2007; Wilson & Knoblich, 2005), inferring others' intentions (Fogassi et al., 2005; Hamilton & Grafton, 2006; Kilner et al., 2006), and social cognitive behaviors, including imitation and empathy (Iacoboni & Dapretto, 2006). A key question in distinguishing these hypotheses is the responsiveness of vPM to biological and non-biological stimuli. For example, if it were the case that vPM plays a specific role in social cognition, then we would expect it to show stronger responses to observation of human actors. Results from previous studies of this issue have been mixed (Brass et al., 2000; Gazzola et al., 2007; Kessler et al., 2006; Press et al., 2005; Tai et al., 2004). Symbolically represented actions are an ideal way to separate biological agency from action representation as the arrows do not resemble living agents but, following training, they are tied to specific motions. Thus, our data suggest that vPM does not respond specifically to human actions. Instead, vPM responses appear to be both flexible and dynamic, driven most strongly by action cues that are familiar from previous experience. This finding is in line with a theory recently advanced by Schubotz, who suggests that activity within the premotor cortex during action observation serves to predict ongoing, familiar events (Schubotz, 2007). The present findings are also compatible with the notion that vPM is involved in motor preparation, both implicit and explicit, for familiar actions (Grèzes & Decety, 2001; Harrington et al., 2000; Rizzolatti & Craighero, 2004).

In contrast, temporal regions, including posterior superior temporal sulcus (pSTS) and inferior temporal gyrus (ITG), demonstrate an almost opposite response profile to vPM with respect to prior experience and the presence of a human model. These temporal regions responded most robustly to the presence of a human model, regardless of prior physical experience. A well-established literature has demonstrated robust activity within posterior temporal regions (including pSTS, pSTG and ITG) during observation of biological motion (Allison, Puce, & McCarthy, 2000; Beauchamp, Lee, Haxby, & Martin, 2003; Grossman & Blake, 2002; Puce & Perrett, 2003).

One interpretation is that pSTS and pSTG (posterior superior temporal gyrus) are critically involved in the automatic identification of animate entities in the environment at a very early level of visual processing (Schultz, Friston, O'Doherty, Wolpert, & Frith, 2005). Reliable activation of STS during tasks designed to explore properties of action resonance has resulted in the inclusion of STS as a component of the human mirror neuron system (Gazzola et al., 2007; Iacoboni & Dapretto, 2006; Keysers & Gazzola, 2007; Kilner et al., 2006). However, taking the present findings into account, it appears that STS's contribution to action resonance results from the observation of another human or biological form, not from action cues. This result is consistent with recent data that demonstrate that observing and imagining moving shapes activates premotor and parietal components of the AON, but only observation of moving entities that participants construe as animate leads to STS activation (Wheatley, Milleville, & Martin, 2007). We suggest that STS is involved in the visual analysis of socially relevant conspecifics' actions, and this processing subsequently feeds into premotor and parietal mirror neuron areas, but also to other brain regions for teleological processing (Csibra, 2007). Such an account of pSTS's involvement in person processing cognition is in accord with a recent meta-analysis performed on this region's functional profile (Hein & Knight, 2008). This means we should not just consider STS to be an input to the human mirror neuron system, but it instead has distinct functions of its own, especially with regards to social cognition.

It is important to consider how these new data relate to previous studies that have reported contradictory results regarding the AON's response to human and non-human action cues (Gazzola et al., 2007; Kessler et al., 2006; Tai et al., 2004). A persistent problem with many previous studies examining questions of action resonance is the issue of familiarity or experience with the action being observed or cued (de Lange, Spronk, Willems, Toni, & Bekkering, 2008; Gazzola et al., 2007; Tai et al., 2004). Prior work performed with dancers has demonstrated that the more physically familiar an action is, the more the vPM responds when observing that action (Calvo-Merino et al., 2005, 2006; Cross et al., 2006, 2009b). It is thus likely that the discrepant results concerning vPM activation in response to observation of actions featuring human and non-human cues are a result of different degrees of experience with an action or action cue, and not the biological status of the agent, per se. In the present study, we have sidestepped this issue by training participants to perform complex sequences of dance movements that were entirely novel before the study began. Our findings that the premotor cortex responds more strongly to training than to the presence of a human model, and that posterior temporal areas respond to the presence of a human model but not to training, suggest that the AON comprises dissociable components involved in different aspects of action cognition. In particular, we suggest that activation of vPM does not necessarily reflect selective processing of human-related action stimuli. Instead, the present data emphasize the impact of motor familiarity on vPM responses and the presence of a human model on posterior temporal responses.

Implications and practical applications for dancers and beyond

At its essence, our laboratory's work with dancers is basic science research. However, findings from this basic research nonetheless have the potential to inform the way dancers and dance instructors approach their work. With both expert and novice dancers, we observed that participants showed stronger and more finely tuned neural responses within the motor areas of the brain when watching movements they had previously physically experienced. These results are corroborated by data recently reported by Aglioti and colleagues, who examined the corticospinal responses of professional basketball players and coaches observing a player making free shots (Aglioti et al., 2008). These authors report that, while the motor systems of elite athletes and expert observers are activated when watching actions belonging to their area of expertise, only the elite athletes demonstrated the ability to discriminate between accurate and erroneous performance, based on observation alone. Aglioti and colleagues conclude that only actual physical practice, which engenders embodied motor expertise, can transform an individual into a truly expert observer of skilled actions.

For teachers of dance, one suggestion might be to keep as active as possible in the instruction process, in terms of being able to perform all the desired movements at the most expert level possible. Although this suggestion might seem somewhat obvious and simple, it could facilitate an instructor's ability to more quickly and accurately diagnose and correct mistakes in dancers' movements. Intuitively, the research findings also suggests that dancers, particularly current dancers, as opposed to former dancers who have been out of the studio for years, might make the best dance instructors and evaluators, since their brains and bodies are highly and regularly practiced at matching action with perception (see also Chapters 1, 4, and 5 by Schack, Bläsing, and Puttke, this volume).

For dancers, the research findings that could have the most appeal and potential for studio applications are those concerning observational learning (Cross et al., 2009b). Although it is the case that actual physical practice is better than mere observation for constructing neural and behavioral representations of new actions (e.g., Aglioti et al., 2008; Calvo-Merino et al., 2006; Cross et al., 2009b; Frey & Gerry, 2006), it is nonetheless striking that simple observation can have significant effects on behavioral performance and activity within the AON. This suggests that dancers can continue the learning process even while waiting at the side of the studio for a turn to execute a combination, or, more importantly, when unable to rehearse because of physical injury (for impressive examples, see Chapter 5 by Puttke, this volume).

Indeed, Johnson-Frey presents a compelling case for speeded recovery from neurological injury (in this case, a cerebral vascular accident, or stroke) with the concomitant use of action observation and active action simulation, which is somewhat similar to the procedure we employed in our study with expert dancers (Johnson-Frey, 2004). Recent work with healthy older adults learning to encode new motor memories lends additional support to the idea that observation of actions, in concert with physical performance, can lead to more robust memory traces and motor learning (Celnik, Stefan, Hummel, Duque, Classen, & Cohen, 2006; see also Chapters 1 and 4 by Schack and Bläsing, this volume). Considered together, this research suggests that observing can help dancers to maintain choreography in their bodies, and observing while simultaneously imagining themselves performing might aid this process even more, as well as potentially facilitate recovery from physical (or neurological) injury.

Concluding remarks

As a final comment, it is important to note that "dance neuroscience" research did not necessarily stem from a desire to investigate how the experience of being a dancer influences the brain. Rather, neuroscientists have turned to dancers as a valuable human resource in possession of a rich skill set who can be studied to address broadly relevant issues of how the human brain coordinates perception with action. Neuroscientists' fascination with dancers will undoubtedly continue, as we seek to further characterize the sophisticated neural structure that underlies the complex choreography between action and perception.

Acknowledgements

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10 Research and choreography

Merging dance and cognitive neuroscience

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I am passionate about dance and cognitive neuroscience, and I am fascinated by the potential of crossing the border between these two fields. At Cinedance in Amsterdam in spring 2006, I first mentioned the term *experimental choreography* in a presentation to describe my scientific and artistic practice. For this, I simply concatenated the titles of the two disciplines I have gained experience in into one expression. In this chapter, I first define the term "experimental choreography" in order to provide a basis for further discussion. Dance and neuroscience are two disciplines with opposing methodologies. Thus, I describe their contemporary approaches, and point out the methodological changes in each individual field over the last couple of decades that have made them very attractive to combine – despite some pitfalls and red flags. I also describe some of my own scientific studies that led to the idea of experimental choreography, outline assets and challenges of past and future examples of experimental choreography, and describe activities specific to the research project "Watching Dance: Kinesthetic Empathy", which myself and researchers from four other universities across the UK are currently engaged with. Inevitably, the research examples from the Watching Dance project that I present are at different stages, with some of them being in their early phases. However, this research project is essential for experimental choreography as it links qualitative audience research, quantitative neurophysiology and choreography (for details see www.watchingdance.org). In a broad sense, all of the studies in this chapter are related to effects of expertise with regard to the *performer*, the *spectator* or the *researcher*, all of which participate in, and contribute to, experimental choreography. I therefore speak of the trilogy of effects of expertise, and organize the chapter likewise; starting with research on the effects of expertise of the performer. For this, I present research in which I studied dancers' expertise in mental transformation and their sensory perception of bodies in space. The aim was to increase our understanding of how we perceive and mentally represent bodies by comparing data from novices with data from dancers as experts. Following the performers' expertise effects, I propose effects of expertise in a frequent dance spectator. The question is, in what respects do experienced spectators perceive a dance performance differently from novices? To conduct this type of research, it becomes evident that the expertise of the researcher in data gathering and observation is important. This constitutes the final part of this chapter.

Experimental choreography

In this chapter, I introduce the term *experimental choreography* to describe a way in which dance and cognitive neuroscience can be combined to build a coherent research purpose. Experimental choreography is not yet a well established term. In general, it is used to refer to a particular type of work in dance as well as other art forms (e.g., experimental music). Usually, these are abstract works that are non-narrative and formal in nature, and arose by a practice constituent of "try-outs", playing, improvising, exploring, and trial-and-error approaches. In most cases, experimental practice in the arts contains more disparate actions than those seen in the systematic experimental approach applied in scientific research. Clearly, scientific research still has priority over research in the arts (e.g., in terms of the amount of governmental funding received). However, it is not my intention to validate one over the other. Borgdorff (2009) published a profound reflection on the political perspectives of research in dance and the basic sciences. In accordance with the author, I encountered corresponding research activities in both fields. For example, artistic and scientific research have often been distinguished by the general view that research in basic science is hypothesis-led whereas research in the arts is discovery-led. The unexpected, intuition and experience, however, also play an important role in science, as will be explained later in this chapter. Nevertheless, I feel at unease with the general use of the term "experimental practice" in dance and propose to confine "experimental practice" to a particular form and stage of research in dance as in other scientific fields. Scientific research asserts methodological pluralism. Thus even in science, research practice and experimental practice are not interchangeable terms. The term "experiment" comes from the Latin *ex-periri*, meaning "to try out". It is important to recognize, however, that over the last two centuries, the experiment has become a very distinguished form of scientific enquiry.

In an experimental paradigm, the relationship among defined variables is investigated. The experiment is designed to measure the effect of at least one (independent) variable on another (dependent) variable. The statistical analysis of the data, partly determined by the experimental method, then allows the scientific researcher to infer the causal role of variables within a certain level of confidence. Inferring differences measured in the dependent variable as effects of experimental variations in the independent variable is a systematic differential approach, and it stands in contrast to merely playing with randomly or intuitively selected variables. Thus, a clear distinction between practices in research and "experimental" work as encountered in the arts is necessary. I suggest that it is therefore more appropriate to use the terms *improvisation*, *intuition*, *trial-and-error*, *exploration*, and so on for non-systematic experimental practice, although all of these activities can also happen during a *systematic*, *scientific* experimental approach. This distinct declaration of the actions in artistic practice would definitively help to clarify and thus consolidate artistic practice as research.

So far, when scholars are comparing artistic with scientific research, the focus is typically on whether artistic research satisfies the criteria that the world of academia broadly agrees on for what is generally understood as scientific or academic research. Such an approach is clearly driven by standards from scientific research and ignores possible inputs from other novel research disciplines. To start with however, I am referring to research criteria myself by defining experimental choreography based on a scientific perspective. Experimental choreography is a creation that is inherently driven by the three scientific research principles: the aim of conducting *original* research, the use of a differential approach that allows an empirical *analysis* of the investigation undertaken, and an increase in our *understanding* of the subject investigated. (For further criteria see bullet points on the following page). In the best case, the acquired knowledge crosses over the borders of its own field of research. Personally, I am interested in research outputs that contribute to our understanding of the cognitive and sensory processes in the human brain.

Dance is an excellent tool to study these processes as many aspects of cognition and sensation also appear in dance. For example, *phrasing* plays an important role in language comprehension. In choreography, both the phrasing of the movements and the phrasing of the piece as a whole exemplify how we create meaning. Thus, dance can be a useful artefact to experience and to study how the brain deals with a chain of information, and how we understand and process verbal as well as non-verbal signals. In addition, recent trends in dance are particularly suitable for studying the cognitive and sensory processes of the human brain. So-called “conceptual” or “non-dance” performances have strengthened the kinship of cognitive neuroscience and choreography. Husemann (2009) describes non-dance as

> . . . a metadance, which critically reflects its own media through practice and offers the experience of this reflection to the spectator. Just as dance takes a critical look on itself, the spectator’s perception gets an introspective dimension: He/she steps out of his/her watching and experiencing to reflect his/her own perception.

The author also suggests that non-dance has created a positive potentiality where production and reception can happen and reflect themselves commonly through the withdrawal of dancing in dance. Xavier Le Roy’s repertoire is probably the best known example of a skilful experimental choreographic approach, probably influenced by his practical experience in research prior to his career in performing. For example, in E.X.T.E.N.S.I.O.N.S., Le Roy simultaneously denotes the body's portrayal and questions related to thoughts about the body. The choreographer understands choreography as the possibility of putting the choreographic working process, the reflection about the body, and its representation, on stage. Importantly, after a period of an introspective *intra*disciplinary research focus (e.g., researching the questions of choreographic practices with artistic research practices), we can take a further step outside the recursive questioning within each discipline: experimental choreography. In fact, the works of Le Roy, the coherent research approach of the company Emio Greco|PC and several other outstanding works by diverse artists (e.g., Ivana Müller's *While We Were Holding It Together*) point in that direction. With a critical look at topics beyond dance itself, they enhance our understanding of the human mind through experience with their works as spectators, as well as through their research outputs in other formats (in the case of Emio Greco|PC). However, we have to be patient; artistic research is still an emerging discipline.

So far artistic research is used to describe a quest for fundamental understanding and development of practice within the artistic discipline. For artistic research to broaden our understanding of the world and ourselves along the lines of scientific research it has to fulfil the following five points:

- *Originality:* Academic research requires original investigation to be undertaken in order to gain knowledge and understanding. This is mostly with regard to the questions, problems and issues of the work, i.e., *what* is being investigated.
- *Rationale*: The rationale of the context of the study, *why* something is being investigated, should be clear, in reference to previous research and situated not only within (i.e., development) but beyond its own discipline.
- *Methodological (experimental) approach:* There is no exclusive methodology for academic research, and the choice of method does not determine its validity as academic research. However, because various methods can be applied in research, *how* the research has been conducted should be transparent. Nevertheless, in experimental choreography, a systematic differential approach ought to be adopted, while methodological pluralism should also remain so as to uphold lively review and criticism.
- *Accessibility:* There are many different forms that the research output can take. It may appear in the form of a presentation, performance, documentation, etc. The coherence of the content and the dissemination of the research are more relevant than *which* form it takes. What is important is the constituent of a cognitive or sensory experience, measurable or observable from either outside (by the researcher) or inside (from subjective experience).
- *Truthfulness*: The elements of ethical conduct are hardly ever mentioned in comparisons between scientific and artistic research. Truthfulness as notion of authenticity in dance performance as well as ethical standards in the field of dance education have been relevant aspects. However, once

experimental choreography is established, truthfulness with regard to the aims of the investigation and ethical standards regarding the knowledge of the spectators (e.g., whether their attendance at a performance is part of an investigation), are important elements that have to be considered.

Some of the above requirements for artistic research touch on interesting subjects that open up new fields of research investigations. For example, the role of authenticity in performance and perception is unclear (e.g., intended play versus emotional experience) and has yet been disregarded in experimental studies. However, this is as much as I want to go into the argument about what research is in this chapter. The focus will instead be on examples, as well as the problems and challenges that we encounter when we merge dance research with neuroscience. I focus on neuroscientific issues that are relevant for understanding the perception and representation of the human body in the brain by the use of dance. To do this I describe *how* the human body is perceived and *why* using dance reveals excellent opportunities for scientific research. Further, I show *which* possible forms the outcomes could take by aiming for experimental choreography as a means by which scientific research can be implemented with dance.

My understanding of experimental choreography is that of interdisciplinary collaborations between dance and neuroscience; both the art of making dance as well as the art of doing science will be affected, as will evidently their outcomes. Thus, experimental choreography should not mean solely acquiring scientific knowledge by the use of dance (i.e., a dance performance illustrating scientific outcomes) nor should it be to "perform" scientific practice (i.e., representing a scientific laboratory). On the contrary, one may ask: Why not create a dance piece that provides valuable empirical data? Or, why not create a performative event that fulfils the identical aims as a particular research into neurophysiology? The idea of experimental choreography is indeed to pursue an empirical quest, meaning that conservative methodological approaches may not be sufficient to investigate the brain's response to watching dance. If we want to acknowledge the importance of the complex real-life situation of a dance performance, new methodologies need to be considered and developed. This will – if successful – ultimately impinge on our understanding of empirical research.

To summarize, the term experimental choreography describes choreography making by the use of an experimental design, as well as dance performances that are created with the purpose of being used as experimental stimuli in a scientific experiment. Ideally, dance and neuroscience share a topic of investigation whose questions can only be answered by addressing it from both fields. There are not yet many examples of experimental choreography. Nevertheless, in the UK, several funding bodies have already supported successful encounters of art and science, in particular related to medicine. However, I have not yet encountered a performance that has managed to create both, dance and scientific research in one.

Dance and neuroscience

The recent popularity of dance in the field of cognitive neuroscience is rooted in the discovery of *mirror neurons* by Rizzolatti and his team (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Over a decade ago, these researchers made an astonishing observation: Neurons in macaque monkeys' brain were signalling both when the monkey reached for and grasped the food, *and* when he was just watching the experimenter executing the same action. Thus, these neurons were triggered by the motor action independently of the agent. This finding supported the theory of *motor simulation*, and a steady increase in published research papers on mirror neurons in the human brain in the past 12 years or so has followed. (See also Chapter 8 by Calvo-Merino and Chapter 9 by Cross, both in this volume). And here, in the theme of movement observation, is the place where dance has become so convenient to use by researchers. Some of the experiments were investigating motor simulation using dance as visual (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, Hamilton, & Grafton 2006) or motor (Brown, Martinez, & Parsons, 2006) stimuli in brain imaging experiments. Other studies have used the presentation of gymnastic movements (Munzert, Zentgraf, Stark, & Vaitl, 2008) to probe the theory of simulation. Behavioural studies also have compared dancers as experts versus novices to examine cognitive processes such as body representation (Ramsay & Riddoch, 2001), movement representation (Bläsing, Tenenbaum & Schack, 2009; see also Chapter 4 by Bläsing, this volume), mental transformation (Jola & Mast, 2005) or visuo-motor coupling in motor control (Golomer & Dupui, 2000).

With the sound understanding of dance, but also especially in view of the papers mentioned above, it is clear that dance is an immensely rich source for studying the brain processes involved in movement execution, perception and bodily expression, all inclusive of elements of human interaction. Therefore, researchers also draw on dance in motor synchronization (Zentgraf, Pilgramm, Stark, & Munzert, 2008), as well as on dance as a crucial indicator for evolutionary factors (Brown et al., 2005; Bachner-Melman et al., 2005). In contrast to other sport or daily life activities, dance is mostly object-unrelated. Several dance styles such as classical ballet have a rather strict formalized movement vocabulary (see Chapter 5 by Puttke, this volume). However, contemporary choreographers seek the unknown, or as Cunningham suggested: "Every artist should ask . . . what is the point of doing what you already know?" (Bremser & Jowitt, 1999, p. 95). The current ideal, which is reinforced probably also by a change in programme to introduce dance as a discipline in higher education and research institutes, is to develop and create original movement vocabularies and performance forms. Thus, if we want to make use of the full potential of dance to study human interaction and cognitive processes, we should include dance forms with contemporary, post-modern or conceptual features.

The number of publications using dance in neuroscience as well as the numbers of dance scholars referring to substantial neuroscientific work (e.g., Foster, 2008) is remarkable. Scientific interest in dance is increasing. This is astonishing, considering that since the 1950s research in psychology has particularly focused on cognitive processes of reasoning, thinking, language and vision, while ignoring the human body as a source of information. For several decades in cognitive science the brain was, and still is today, the focal point of study, while motor-sensory aspects of the body have remained largely ignored. It is probably not until neuronal computing emphasized the importance of embodiment that the perspective has changed. Today, the body is regarded as more relevant than a mere sensory boundary, an input tool, where information about the environment is gathered and then processed by the human brain (see Chapters 3 and 4 by Cruse & Schilling and Bläsing, this volume). Clearly, the way the body functions and the way it is organized, has an affect on how we perceive and interact with the world around us (e.g., Pfeifer, Bongard, & Grand, 2007). The body is also an instrument of affective expression, social and spatial cues, in verbal as well as non-verbal interaction (Shipley & Zacks, 2008). Thus, with these current topics in mind, it is clear why cognitive neuroscience is interested in dance, and it is hoped that research in dance can move further alongside research in cognitive neuroscience. I am positive about this fruitful combination. So far, my experience in this interdisciplinary field so far has been very encouraging, if also challenging. Dance and neuroscience are inextricably intertwined, and it is an exciting journey down this route.

First, one might ask why the two seemingly dissimilar disciplines get together at all. Dance has a cultural importance in evolution. Thus, it is inherently linked to major neuroscientific precursors, such as the mirror neuron system. Indeed, some have argued that mirror neurons provided the evolutionary springboard for the emergence of language and culture in hominids. One of the most visible promoters of this idea is Ramachandran. He goes as far as to predict that mirror neurons will do for psychology what DNA did for biology: "They will provide a unifying framework and help explain a host of mental abilities that have hitherto remained mysterious and inaccessible to experiments" (Ramachandran, 2000). The author signifies mirror neurons and imitation learning as the driving force behind "the great leap forward" in human evolution. Thus, was the cultural practice of dance performance established *because* of the mirror neurons, or did the mirror neurons develop with the cultural practice of dance?

Second, why do the two fields show an interest in kinship today? I briefly mentioned the trends in the topics within cognitive neuroscience above. In dance, it is the recent conceptual dance works that open up numerous empiric research possibilities. Conceptual dance emphasizes cognition and the sensory awareness of the spectator rather than a direct presentation of the performers' technique. In short: themes of body perception and representation as well as the element of indirect reception bring the disciplines very close to each other.

Nevertheless, what are the most challenging aspects in the bonding between dance and cognitive neuroscience? Dance is a sensory experience for the dancer himself, yet in performance it is thought to also please the observer. The dancers evoke sensations within the observer, and, together with self-reflecting processes, the observer might infer the performer's intended performative state but can also gain insight into his or her own emotional states and thinking. A dance can be regarded as an external representation of complex mental processes, which supports the use of dance to study the human brain. However, in my experience, dance artists and scholars express strong reservations about productions that refer to experimental choreography. The criticism is directed towards the aesthetic value. These notions are probably nourished by uninventive science-related dance works. I will refer to this point later. Yet also for the scientific investigation, aesthetic factors may play an important role, especially when using dance or any other art form as stimulus material. Using dance, one may control the stimuli for movement parameters, but to create aesthetic stimuli and to be able to classify the stimuli to certain types (e.g., female versus male movements in the study of Calvo-Merino et al., 2006; see also Chapter 8 by Calvo-Merino, this volume), choreographers and movement analysts need to be involved. However, scientific research generally does not consider aesthetic components on a professional level, unless it is part of the hypothesis itself. Scientific research is not about liking or disliking. One of the main scientific aims is objectivity, and experimental research is a useful tool with which to accomplish it. The purpose of experimental design is to fulfil certain established requirements. In an experiment, variables are balanced and manipulated with regard to the hypothesis and any other factors that are suspected to have a systematic effect on the measured variables are attempted being controlled. Even though one may agree with the assumption of aesthetic pleasure as a subjective experience, the fact that it is an important aspect of dance cannot be disregarded. Thus, using dance in research for the purpose of creating experimental stimuli means that its aesthetic value has to be taken into account.

Objectivity has so far been a relevant difference between dance and neuroscience. However, attempts to compare cognitive neuroscience and choreography by outlining the steps of the process within the two practices have not been successful. Where is the line between practice-based research in dance and empirical research in cognitive neurosciences? Empirical research involves both theory-based hypothesis as well as practice-based activity, such as running an experiment. Experience gained by practice is important for designing and conducting an experiment. It also informs the researcher of how to better design further enquiries, for example via participants' instantaneous feedback. Thus not only the results but also the practice itself can lead to new experimental ideas and models. Recently, subjective reports have been involved more often in the data analysis and interpretation in neurophysiological studies (for example, Calvo-Merino, Jola, Glaser, & Haggard, 2008; see also Chapter 8 by Calvo-Merino, this volume). Also, many substantial discoveries were made by "mistakes" or "chance" during experimentation. For instance, the finding of mirror neurons was a fortuitous detection during the experiment. The researchers noticed with astonishment that the neurons of the monkey kept on firing while the experimenter grasped the objects on the table for the next trial in the test. In contrast to choreography, however, chance operations are generally not regarded as the ideal informative element in scientific practice. The use of chance in science is to omit systematic changes, whereas chance procedures played an important role in the dance performances of Cunningham – in particular in the 1960s with Cage (Brown, 2007).

Art has often been inspired by science, but we have to be patient for science to be thoughtfully inspired by art. For this, it is useful to focus on the differences between science and the arts in regards to the aesthetic valuation and the experimental design. While aesthetic valuation in the arts is one of the main criteria, it does not play a selective role in scientific research. While cognitive neuroscientists use an established method for their investigations, each choreographer seems to develop his or her own individual practice. This is an interesting aspect as it emphasizes how different forms of practice produce different forms of works. The relationship between practice and outcome is important in science, while in dance it has been used as well as investigated in a much more playful way.

To summarize, in an interdisciplinary approach, changes within a discipline are inevitable. Crossing disciplinary borders makes us look at the research from a different perspective, which evokes new attitudes. Instead of indexing the differences and parallels in research practice between dance and cognitive neuroscience, I will give a few examples below for how dance and neuroscience can and have been combined in order to investigate cognitive and neuronal processes. However, one has to set aside some prevalent expectations and common restrictions within both areas. In short, it is helpful to retain a certain level of naivety. So far, I have highlighted the two most important and contradictory ones: the aesthetic considerations and experimental design. The benefit of radically combining dance and neuroscience is the potential to change the way in which we look at (and validate) the outcome of choreographic research on one hand, and how we implement aesthetic considerations into experimental methodology on the other hand. It seems that both areas can increase their value by the use of the other. Ideally, this will provide new insights in the understanding of the nature of the human being.

Trilogy of expertise effects

The dancer

Testing experts in a series of cognitive tasks is a way to investigate the brain's neurophysiological network. Clearly, dancers are experts in motor control and emotional expression. If dancers, for example, show increased ability in one cognitive task, such as spatial attention, their performance can be compared with other tasks to extract factors involved in spatial attention. However, dancers' expertise might just reflect pre-existing, innate abilities (Bachner-Melman et al., 2005) and thus not necessarily a product of their training. Further, the aim of comparing expertise effects across different tasks is to probe a theoretical framework. The best-case scenario is an iterative process where findings will feed back to dancers' understanding of their training (see Figure 10.1). In the text below I describe experiments on dancers' effects of expertise that led into the solo performance "Aahh. ." (2008, see expertise effect of the researcher).

Mental manipulation

There are probably three main abilities that dancers are trained in beyond muscular strength and flexibility training: spatial awareness, body representation and perception of time. Dancers have to copy steps quickly, which means that they have to transfer visual inputs into a motor code. Having done so, they also have to quickly modify motor codes, for example by changing the movements from the right to the left side, or performing them in a different direction in space (see Chapter 5 by Puttke, this volume). It is also crucial that the performers are very sensitive to rhythm and timing to achieve

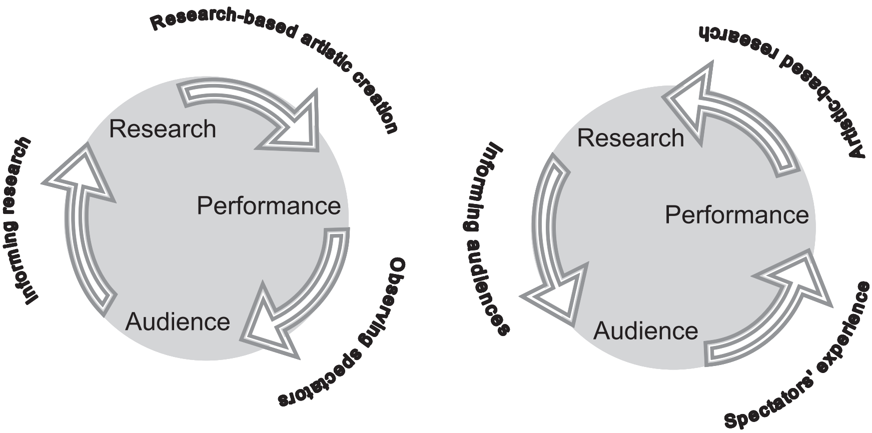

Figure 10.1 Turntables indicating bi-directional itinerary process in experimental choreography.

synchronization with partners as well as for accurate expression. For instance, a circular arm movement with a quick start and a slow ending has been described as an "impulse" (Goodridge, 1999). This action is perceived differently if executed with a slow start and a quick ending – and is called an "impact" (Pollick, Paterson, Bruderlin, & Sanford, 2001). These factors – space, body and time – make it very interesting to study dancers as experts. To improve these abilities, dancers mentally rehearse their movements as part of their training. They use imagery to achieve higher movement quality (Golomer, Bouillette, Mertz, & Keller, 2008) and indeed dancers show more deliberate use of imagery than non-dancers (Nordin, Cumming, Vincent, & McGrory, 2006). Does this everyday training in mental transformation and mental imagery make dancers experts in cognitive tasks where mental transformation is required? The interest of this question is twofold. First, individual differences in mental transformation have previously been reported. For example, differences have been found between males and females, with males performing better (Kucian, Loenneker, Dietrich, Martin, & von Aster, 2005), as well as between sport experts and novices (Ozel, Larue, & Molinaro, 2004). This raises the question of whether mental transformation is sensitive to expertise in dance. Second, several researchers have found evidence for different networks involved in mental transformation of bodies and objects. Thus, is the mental training of dancers specific to the ability of mental manipulation of bodies without any general advantage of mental transformation (e.g., of abstract objects)? If any mental processes are involved in both body and abstract object manipulation, dancers should show increased abilities in mentally rotating both bodies and objects. I conducted two studies on mental transformation processes with dancers and non-dancers to investigate mental transformation processes of objects and bodies. Both groups performed a mental object rotation and egocentric body transformation task. Before I report the results, please see some background information on mental object rotation and egocentric body transformation below.

The mental rotation task conducted by Shepard and Metzler (1971) is of historical significance in the field of psychological research. The authors were the first to show evidence that a cognitive process can be objectively monitored. The experiment consisted of pairs of abstract cubes presented in different orientations on the computer screen. The participants were asked to indicate whether the two cubes were identical or not. The response time of the participants' judgements increased linearly with increasing angular disparity between the two cubes. According to the authors' conclusions, the response times indicated that the mental processes corresponded to real (manual) rotation of the objects. The underlying assumption is that the bigger the cognitive load involved (e.g., the more rotational steps are necessary), the more time is needed. This study was groundbreaking as it showed that, with the appropriate experimental design, we are able to look into the "black box" and make inferences about the processes of the human brain.

Several follow-up studies on mental rotation showed that the task was easier with familiar stimuli than with complex novel or meaningless stimuli (Leone, Taine, & Droulez, 1993). However, in contrast to the linear increase for objects, mentally transforming drawings or pictures of human bodies did not show the expected mental rotation costs for increasing angular deviation from the default upright position (Parsons, 1987). Thus, egocentric body transformation and mental object rotation were regarded as two distinct mental activities. Following the period of intense behavioural and psychometric testing, a number of pioneering methods such as functional magnet resonance imaging (fMRI) or transcranial magnet stimulation (TMS) were established (for methods, see Box 4.1 in Chapter 4 by Bläsing, this volume). fMRI allowed non-invasive picturing of the blood-flow of an active human brain and thereby locating of cognitive processes in the brain. Based on the brain areas found to be active in an fMRI scanning experiment with body stimuli, the authors also indicated different neural networks were involved in the transformation of bodies than those used in mental object rotation (Zacks, Vettel, & Michelon, 2003).

An often-reported difference between mentally transforming bodies and objects is the participants' frame of reference. In egocentric body transformation tasks, participants are shown one human figure and are asked to judge which arm is outstretched. Thus, participants have to change their frame of reference to match the person being viewed. In mental object rotation, however, the participants' frame of reference remains stable while two simultaneously presented objects are aligned along a particular axis. Thus, it is of relevance to investigate whether similar processes are involved when the change in the frame of reference remains identical between the two tasks. We thus conducted a study to compare dancers with novices in two mental rotation experiments while controlling for the frames of reference (Jola & Mast, 2005). For this, the stimuli were presented from the front as well as from the back.

In our study, participants performed two tasks in a counterbalanced order. One task was to compare two abstract cubes presented on the computer screen in different orientations (as in the study by Shepard & Metzler, 1971, described above). The other task was to indicate whether the left or right arm of a body drawing that was shown on a screen presented in different orientations was outstretched (as in the egocentric body transformation task by Zacks et al., 2003, mentioned above). We found that dancers were no better than our control group in either of the two transformation tasks tested. This result suggests that dancers do not have better mental manipulation abilities in general. However, we found significantly shorter response times than expected for both groups in the mental transformation of bodies in one particular rotation, namely front facing, inverted bodies (see Figure 10.2). The same tendency was found in the object category. With regard to the mental rotation hypothesis, one would expect that the participants made a mental rotation of 180 degrees in depth and 180 degrees in the plane axis from the

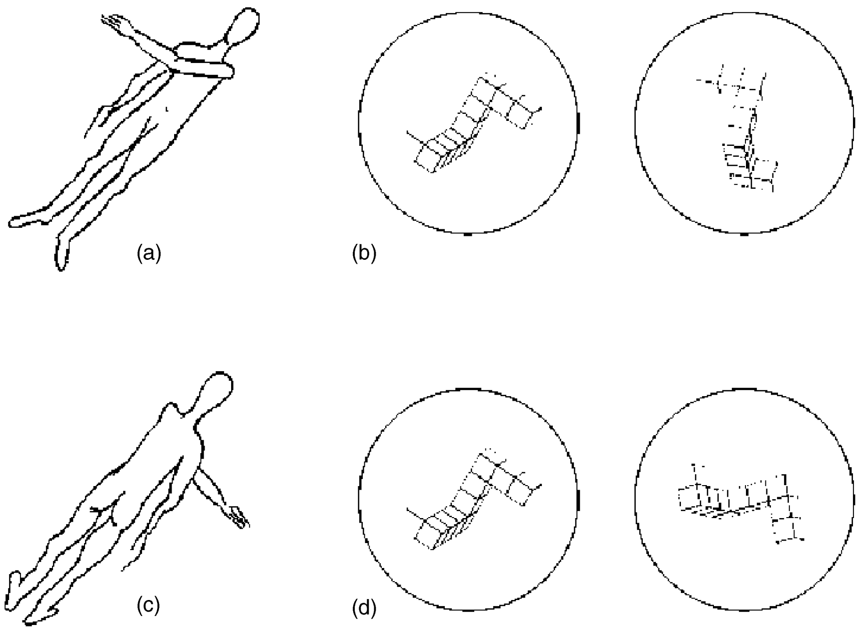

Figure 10.2 Example of the stimuli used in the mental rotation task (Jola & Mast, 2005). Body drawings requiring mental transformation of 45 degrees rotation along the plane axis (c) and additional 180 degrees in depth (a) to align with the natural upright position from the back. Abstract cubes requiring mental transformation of 45 degrees rotation along the plane axis (b) and additional 180 degrees in depth (d) to align with each other. (Reprinted with permission from Jola, C., & Mast, F. (2005). Mental object rotation and egocentric body transformation: Two dissociable processes? *Spatial Cognition and Computation*, *5*(2&3), 217–237 by Taylor & Francis.)

inverted to the natural upright back view. However, the response times were much shorter, as if the participants mentally flipped themselves or the object backwards. This is in correspondence with the suggestion made by several authors that participants imagine spontaneously rotating along direct paths (Parsons, 1987) and that visual features like familiarity are responsible for a change from incremental, small successive steps to a quick flip along the shortest path (Ashton, McRarland, Walsh, & White, 1978; Robertson & Palmer, 1983). For example, when participants have to match their perspective to an inverted front-facing figure, they do not mentally rotate incrementally 180 degrees in the plane axis (from inverted to upright) and 180 degrees in depth (from front facing to back facing) as would be predicted along the lines of mental rotation. The clear reduction in response time, and also participants' reports, showed evidence for a mental flip backwards. This means that participants seemed to merge incremental steps into a quick flip when matching their perspective from the default upright position to an inverted figure presented from the front. However, it remains unclear whether the "quick flip" simply reflects a quantitative advantage for some mental rotation operations that have been over-learnt because of the visual familiarity of one's own and other bodies, or whether it reflects a qualitatively different, non-spatial way of manipulating body representations.

However, and this is the most surprising fact in our data, because of the short time taken in mentally rotating the inverted front-facing stimuli, the axis of rotation seems to be known by the participants before the stimuli are actually rotated or flipped onto the canonical axis. How is this possible? Bodies, as well as familiar objects, are a special set of stimuli as they possess an inherent axis that is canonically aligned with respect to the environment in a way that abstract objects need not be. The kinesthetic body experience may be a relevant factor in mental transformation, and it seems that even novices are experienced enough to switch between the different sensory modes of vision (perception of the drawings) and proprioception (sensation of flipping backwards).

Sensory transfer

In a follow-up study we investigated dancers' expertise in proprioception (Jola, Davies, & Haggard, in revision). In the study described above, dancers did not show any expertise on mental transformation of *visually* perceived bodies (Jola & Mast, 2005). In the study reported here, however, we found evidence that in contrast to novices, dancers rely more on proprioception than vision to perceive the position of their upper arm in space. Thus, we need to learn more about the flexibility and interplay of different modes of sensory perception – in particular, as the results indicate that dancers have a general tendency to interchange sensory modes.

In the current neurophysiological literature, the term "proprioception" is used to refer to the kinesthetic sense, a set of sensory signals that originate peripherally in the body, and that inform the brain about the positions and movements of parts of the body in space. These signals are thought to derive from muscle spindles, joint receptors, tendon organs and skin receptors. The most studied of these, and perhaps for an accurate position sense the most important ones, are the muscle spindle afferents. When a muscle is stretched, the spindle afferents signal the change in its length, and the velocity of that change. However, muscle spindles only play a partial role in the overall experience of position sense (see Goodwin, McCloskey, & Matthews, 1972), and other senses such as vision can contribute. A functional understanding of the integration of these different sensory signals in position sense is essential to comprehend the representation of the body. Most studies on position sense have focused on local proprioception only. Yet we sense a coherent representation of the surface of our body as a whole.

It is important to understand how the sensory signals arising from different parts of the body are combined in order to construct this integrated representation of the whole body. That is, local information about the length of each muscle or the angle of each joint can be combined to represent the configuration of an entire limb, or indeed the whole body. The term "body schema" has often been used to refer to an abstract postural representation of the configuration of the body in space (Head & Holmes, 1911). We experience on a daily basis where our body parts are in space, but we have no conscious sensory experience of the actual lengths of individual muscles. Also, relatively little is known about how the brain combines multiple local signals from each point in the kinematic chain in order to produce an overall body representation. For example, a person who reaches under the table to tie their shoelace without looking at it, clearly uses representations of the position of the foot, and of the hand, and is moreover able to relate them in an appropriate way. Another example is that of a dancer on stage rather than in the studio, because in the studio the dancer can visually control his or her body limbs in space and also synchronize them with other dancers by looking in the mirror. However, on stage he or she has to rely fully on the proprioceptive information. Only few experimental studies have systematically investigated how different types of proprioceptive information from one or more body parts are integrated and combined with other sensory inputs such as vision.

Several studies have created conflicts in the integration of different body parts into a whole body representation by manipulating sensory inputs. For example, when participants hold the tip of their nose while experiencing an illusory extension of the elbow induced by tendon vibration, they feel as if their nose has become elongated (Lackner, 1988; see also Chapter 3 by Cruse & Schilling, this volume). This suggests that participants maintain an internal body representation, including information about body part size. Nevertheless, this study also showed that the brain appeared to impose coherence, and this broke down, as the nose was experienced as abnormally sized. Other examples producing physically impossible percepts using tendon vibration include hyperextension of the forearm (Craske, 1977), or physically impossible configurations of the whole body (Lackner & Taublieb, 1984). Thus, the position sense of the body and the body schema is calibrated over time, and is actually provided by the relation of body limbs to each other, particularly when they are in spatial contact (Lackner, 1988).

In the study on dancers' expertise in proprioception (Jola et al., in revision), we used a position matching task, which is an established method for investigating the spatial representation of the body (von Hofsten & Rosblad, 1988). We measured how well dancers perceived the position of their index finger in space given different sensory information, and compared it to novices. Participants had to indicate the position of their target hand at a range of five locations on a horizontal surface by reaching with their other hand to the matching location underneath the surface. We compared the accuracy of the target matching when visual, proprioceptive or multisensory information was available. For example, in the visual condition, the participant visually focused on the matching point on the table surface in order to match it as closely as possible from underneath, while in the proprioceptive task, the participant was blindfolded and thus had to rely fully on the proprioceptive information. In general, pointing errors are bigger when only proprioceptive information about the target location is provided compared to when the same target location is visually perceived. Also, significant further improvement is found when both visual and proprioceptive information about the target location are available. This suggests that a multisensory combination of visual and proprioceptive information provides a better representation of the position of the hand in space than either sense alone (Haggard, Newman, Blundell, & Andrew, 2000). Ramsay and Riddoch (2001) showed that dancers have an outstanding performance when matching upper body part positions. In contrast to their study, we investigated which aspects of proprioception are superior in dancers. We chose dancers as experts particularly to investigate whether they were better than a control group in combining proprioceptive information from several joints and muscles to generate a superior representation of the overall configuration of the body as a whole. An affirmative answer would suggest that the mind can form superordinate levels of proprioceptive body representation, presumably only as a result of training, and it would reveal the dimensions of its spatial organization. As expected, matching accuracy was better based on visual information than proprioception only. Participants in matching accuracy tasks previously showed a hand bias that is typical for prioprioceptive information (Haggard et al., 2000). This means that the targets are perceived rotated towards the right shoulder for the right hand and vice versa, generating an x-pattern (cross-over effect). Overall, dancers showed a smaller hand bias, meaning their body representation was more coherent. Also the performance of the dancers was less modified by sensory condition. Thus, their body representation seems to be less dependent on the type of sensory information available. It seems that they generate a kinesthetic mental image they rely on even though visual information is available. This is congruent with the finding that dance training enhances the imagery of kinesthetic sensations (Golomer et al., 2008) and that dancers actually use deliberative imagery more often than non-dancers (Nordin et al., 2006). A functional brain scanning study that compared dancers to controls in the position matching task supported the assumption that dancers form visual and kinaesthetic mental images to sense the body in space. Dancers showed a tendency for higher brain activity in visual areas of the brain when no visual information was available, and they also showed higher activity in sensorimotor areas when only visual information could be retrieved (preliminary analysis; data from unpublished Master thesis in Neuropsychology by L. Bezzola, University of Zurich). Further, the same dances showed significant changes in structural brain analysis but not in the expected direction (for further details see Hänggi, Koeneke, Dezzolat & Jänke, 2010).

To summarize, several studies indicate that dancers have a more accurate position sense based on proprioceptive information than novices. However, dancers are not better in position sense in general. This is probably because dancers generate a mental simulation based on sensory information that might be interfering with, or that might be less reliable than, other sensory information, such as vision. The reason for generating seemingly inefficient mental images might not be useful for accurate positioning but might support expressivity of the movement.

The spectator

Two major aspects in studying the spectators' responses to watching dance are the motor sensation and the emotional reaction. The former is based on the idea of motor simulation. As described in the paragraphs above, previous research in cognitive neuroscience using dance stimuli focused on the effects of motor expertise of the professionally trained dancer. In most of the studies cited, the dancers' brain activity was measured while observing familiar and non-familiar movements. However, in a dance performance, some members of the audience are not trained in dance. Spectators do not necessarily have a motor experience with the movements they witness on stage. Nevertheless, these people also enjoy watching dance (for instance, 40% of the questionnaires collected in October/November 2008 at the Theatre Royal, Glasgow, were filled out by audience members with no training in dance). Thus, to what extent can visual experience manifest itself in lack of the related motor knowledge? Is the kinesthetic sensation evoked by the brain's response to watching dance eventually also modified by visual expertise? Besides the motor related sensations, people do watch dance performances because they enjoy experiencing emotional responses. The body movements and expressions of the performers are supposedly emotionally contagious (see Hatfield, Cacioppo, & Rapson, 1993). Spectators' subjective emotions may be directly affected by what they see, or affected by the activation and feedback from synchronization with the facial expressions, voices, postures, movements, and instrumental behaviours of others. In one of the earliest theories on emotion, William James (1890) proposed that people infer their emotions by sensing their muscular, glandular and visceral responses. In other words, the spectators experience a kinesthetic sensation (motor simulation) as well as the emotional response (either directly, by activation, or by feedback from the synchronization) and both combine to form one single experience. However, not much is known yet about the connection between the phenomenological experience (kinesthetic sensation) and mirror neuron activity (motor simulation). Nevertheless, it is worth considering how both motor and emotional sensations are used to infer others' intentions and whether they are probably subsumed to one single process, often termed kinesthetic empathy.

Mental synchronization

For successful social interaction, it is important to understand and anticipate others' behaviours. To infer the intentions of others, we are taking into account different aspects of what we see from the other person, such as posture, gesture and facial expression. Affective body motion has been considered also as an expression of complex mental states. Can dance be a representation of complex mental states? Does a spectator who has acquired a high level of visual expertise in dance infer mental states better than someone who is rarely exposed to watching dance? Can the action be simulated through visual experience, or can repeated exposure to watching dance generate a motor sensation via empathy?

Researchers found that the bodily expression of the spectator interferes with reading the emotional state of the observed in a large number of studies (see Niedenthal, 2007). Niedenthal also suggests that feedback from mimicking the observed subject is a relevant factor for generating a sensation of empathy. When I watch my performers in rehearsals, I simulate their actions independent of whether I have only visual or motor familiarity with the movements. Usually, friends and collaborators who are observing my rehearsals are amused by my head and facial expressions accompanying the dancers. However, spectators do not mimic performers overtly during a theatre performance. Can we assume that spectators mentally synchronize with the performer? Calder and colleagues (Calder, Keane, Cole, Campbell, & Young, 2000) tested facial expression recognition of people with Mobius syndrome, a congenital disorder producing facial paralysis. The authors found that the patients' inability to make facial expressions themselves did not impair detection of emotions from others' faces. However, the lack of facial expressiveness affects social interaction, and these patients often report difficulties in sensing their own emotions:

> I did not know that I could tell people. The body is a transmitter of various clues. I thought the only way I could show people was the voice. Any non-verbal clues were divorced from me. I did not know they conveyed a message. This broadened the gap between them and me. The more I could see and read other people's faces, the more they were different from mine. . . . I did not know what facial expression did and was for. I did not understand it showed feeling and expression.
>
> (Cole & Spalding, 2008, pp. 46–47)

These "Cartesian children", as Cole describes them, do have a mental concept about emotions but no access on the emotional level. It is not until they have learnt to express their emotions with the body, by gestures, that they can overcome the dualism of the body and the brain. Cole's work highlights two major aspects that we consider relevant in our own research project on the spectators' response to watching dance. First, there is the spectators' experience of their own feelings, which seems to be necessary to evoke a sensation when watching dance; and second, a purely scientific approach appears to be inadequate. As Cole presented (December, 2008) the study of neurological impairment requires an empathetic, neurophenomenological approach to the lived experience of others. Cole sees the subjective experience as having the potential to reveal relevant information and should thus be included in the research.

Subjective experiences

Currently, I am part of a group of researchers working on "Watching Dance: Kinesthetic Empathy", a project funded by the Arts and Humanities Research Council (AHRC). This research project is novel in several respects, one of which is our cross-disciplinary approach. We are looking at the audience's neurophysiological and reflective (verbal and non-verbal) responses to watching different dance styles. In particular, we want to see whether people who watch dance on a regular basis show different responses than people who are inexperienced in watching dance. For this, we are combining methods from qualitative audience research (e.g., interviews, participatory workshops) with neuroscience (e.g., quantitative experimental studies).

So far, we conducted three studies using both approaches, neuroscience and qualitative audience research with the same participants. In one study, we measured the activity of brain areas involved in body and motion perception with fMRI. In the other two studies, we investigated the participants' engagement in watching dance with TMS. Both techniques use magnetic stimulation to infer activity of the brain. In the former, participants are lying in a narrow tube while the scanner releases magnet pulses aligning protons in the blood. The flipping back of these protons to their initial orientation can be measured and gives an indication of the oxygenated blood circulation in brain (see Box 4.1 in Chapter 4 by Bläsing). In the latter, we used TMS, which can be used to either activate or interfere with the neural response. We applied single magnetic pulses over the left motor cortex of our participants. This leads to a current in the participant's brain inducing an action potential, which evokes a motor response in the form of a motor potential. If this motor potential is large, a twitch can be observed in the participant's right hand. This twitch is an observable response that can be quantified. From previous research we know that the size of a motor potential is dependent on the cortical excitability and gives an indication of the preparedness or engagement of the motor cortex. Both TMS and fMRI have been used widely by researchers to investigate the neural basis of high level (e.g., thinking) and low level (e.g., early visual perception) processes. More importantly, these factors distinguish our studies from others. This is because, as mentioned before, we are aiming to combine qualitative audience research and neurophysiological approaches. Second, we have the ambition to maximize the ecological validity of our experiments. This means that we are aiming to use real events as visual stimuli, instead of the short video clips used in previous studies. For instance, when we are forced to use videos instead of a live performance, for example in an fMRI study, we use sequences of a dance video that lasts as long as 6 minutes. The analysis of data gathered from such long presentations is far from trivial. Only a few studies have yet used long sequences in fMRI (Hasson, Nir, Levy, Furhmann, & Malach, 2004; Zacks et al., 2001). In the most recent TMS study we went even further by testing the engagement of the participants during a dress rehearsal of *Sleeping Beauty*, performed by the Scottish Ballet in the Theatre Royal.

All the studies we aim for use a differential approach. In order to get as much ecological information as possible, rather than setting the observer in an experimental setting, we only instruct them to "watch". Thus, the qualitative interviews reveal much information on how the performance has been seen and, in particular, which scenes were of relevance for the participants. Clearly, each participant has their own personal approach to watching dance. Thus, it may be important to relate the quantitative data to subjective responses with regard to their own "instructions" (e.g., Zentgraf et al., 2005). Nevertheless, we also compared detailed descriptions of experiences of watching movement with general movement categories, such as Laban's effort categories, and correlated with the participants' neurophysiological response. Laban's *effort categories* (Laban, 1947; Reynolds, 2007) provide a framework for analysing and describing movement qualities (for Laban, see Box 5.1 in Chapter 5 by Puttke, this volume). In our study, we are referring to his ideas to help us establishing a schema of kinesthetic response in the audience. Are the audience's sensations correlated with their brain activity? Can we identify a neural network of Laban's effort qualities in the spectator's brain? The research aims to deepen our understanding of the role of kinesthetic empathy in watching dance, including spectators' experience of Laban's *motion factors* of weight, space, time and flow as well as choreographers' and performers' understanding of factors such as presence. It will provide indications of how to optimize the audience's engagement with dance and will further cross-disciplinary research between the arts and the sciences. Last but not least, it will enhance scientists' knowledge of the role of subjective experiences and also of using complex natural stimuli in contemporary neurophysiological techniques.

The researcher

When running an experiment, the researcher relies on expertise as much as a performer does on stage, or a spectator does when going to the theatre to see a dance piece. The experienced researcher knows how to conduct the experiment; with practice, every step in the actual testing procedure becomes automatic. It also helps if the researcher has an understanding of the relevant factors that need to be controlled in his or her particular field. It is with the introduction of a new technique or method that new proficiency needs to be acquired. Before any relation between data and the underlying neural structures and mechanisms of cognition, emotion and behaviour can be made, the technique has to be probed extensively. Usually, it is only when a technique has been used by a broad community of scientists with clear evidence of how to analyse and interpret the measures that the methodological probing declines. This is important in understanding the position of encounters that merge dance and cognitive neuroscience. Even though on the neuroscience side, established techniques such as fMRI and TMS are used, its combination with qualitative research is still in the early development stages. As with any new methodology, it will require experience to find which way of working is most effective. A period of practice will increase our understanding of how to measure our participants in real-life situations and provide us with the know-how about ways in which we can relate qualitative research with quantitative data from such tools as fMRI and TMS.

An illustrative example of what it means to gain research expertise comes from our real-life testing during a couple of dress rehearsals in the theatre. The dress rehearsal with a huge orchestra playing, a number of professional dancers performing and with the proper light-set and costumes is a unique event with its own schedule. For example, there is no exact defined starting time and thus the applying of the TMS pulses can not be fully preprogrammed. In contrast, flexibility for starting points, block lengths and number of pulses might need to be adjusted during the testing. For example, in any laboratory experiment, technical issues can require a stop and disregarding some data may be appropriate. However, it is not possible to repeat a two-and-a-half hour performance just for the purpose of smooth experimental running. Thus, testing a natural situation means accepting all its inherent unforeseeable events.

Experimental observation

The uncontrollability of relevant factors is the main objection against experimental testing in a natural setting. The description "observation with the use of neurophysiological techniques" probably explains better the form of this kind of investigation than "experiment". In contrast to a balanced experimental design in a controlled setting, as for example in physics, we are observing the spectator – with modern techniques – to uncover factors of relevance. Observation of human (and animal) behaviour was a conventional method before experimental designs became the core procedure to investigate cognitive and neuronal processes. Observation as a scientific method has ever since lost interest and, more importantly, it is no longer acknowledged as a tool allowing valid inferences about cognitive or neuronal processes in the human brain.

What is novel about our latest approaches in the Watching Dance project is that we were not "observing" the participants' response with our own eyes but by the use of TMS. As the participants were watching an existing dance production, the "stimuli" were designed long before our study. The movements were set by a choreographer, and the *Sleeping Beauty* ballet is a reproduction with a traditional narrative. At which particular moments of the show and how (at what intervals, with what method, which brain side, etc.) we tested our participants was subject to four main criteria: the research questions discussed, our scientific understanding of research, knowledge of previous studies, as well as the constitution of the already existing stimuli (the ballet), with the latter being the most constricting element. Now, the data gathered are analysed with regard to the spectators' subjective interview responses. No other study has yet been published with long sequences of dance stimuli or with TMS in a real theatre setting. This is the beginning of a research phase that we hope will provide us with experience in testing and analysing neurophysiological data measured in such real-life scenarios. At this point it became very clear to us that, similar to the performers on stage, we have to rehearse the experimental procedure in detail. Only high expertise in this kind of testing will enable us to respond in a flexible way during the testing with the best possible and reliable data.

Using brain imaging techniques, we have gained enormous experience regarding the human brain. We know which areas are activated in experiments requiring face recognition, perception of body expression, movement and emotion. Now we can turn in the opposite direction and use this knowledge to study human response in a natural scene. Is the response in our motor areas stronger when we see big hand movements than with small ones? Is there a pain-related response when pain is observed even in a non-experimental setting? Of course, the participant could watch a recording of a performance in the scanner, which is also part of our project. With TMS, however, we are mobile and we think it is important to investigate the kinesthetic response of the spectators in a setting that is as close to the real-life situation as possible. Only if we test them in the way the spectators actually see the ballet, can we infer their responses. We propose that it is impossible to measure the responses to watching dance in a laboratory setting. The experienced spectator will suffer from the lack of the different strands of the performative, such as the theatre space, costumes, light, simply everything that is part of a professional performance. It is the event as a whole that gives the spectator the experience and makes him or her go to watch another piece.

Transfer of know-how

We proposed that all strands of a performance are important in testing our participants' response to the dance. However, contemporary choreographers often choose an unconventional space for dance performances (compare Chapter 6 by Zöllig, this volume). We could therefore also imagine a whole performance in a laboratory setting. Several funding bodies support artists to spend a certain period of time in a scientific laboratory to gain a deepened understanding of scientific practice. This experience in scientific laboratories is expected to express itself in the artists' works. On top, the communication between artists and scientists evokes new ideas for scientific investigation. Surprisingly often, the performances instilled by laboratory practice of the choreographer are still staged in common settings, in the theatre.

In the best case scenario, however, the scientific residency of an artist should lead to a two-way interaction, meaning that both the researcher and the artist are engaged in examining their practice. Practice is a term often used in choreography. Clearly, the scientist has to gain practice when applying new methods. How far does or should the practice of the scientist who investigates the perception of dance go? The scientist usually leaves the selection of the movements to the choreographer and the dancers. Yet, the researcher needs to know the factors he has to control for. In the case of our live testing of the ballet *Sleeping Beauty*, we needed to know what will be performed. Is this restricted to the narrative of the dance performance? Or should we know each single step of the choreography to depict what aspects we will be able to measure? We could of course link the measurements of the brain's excitability with the timing in which particular events happen. For instance, we could control for particular movement parameters, such as speed, dynamic, force and frequency. Yet, the movements on stage are never performed in the same way. The quality and intensity of the movements may change while the meaning still remains the same. Even if we make a pre-test analysis of stimuli such as movement parameters, they will probably not be counterbalanced over the whole performance, and they are unlikely to be performed with the exact same quality twice. Thus, only online movement analysis would allow testing without any understanding of the movement parameters involved. It seems helpful if the researcher has an understanding of the movements and the narrative, if movement analysts are involved and if we rely on the subjective experience of the spectator. One important aspect however needs to be considered here: the experience of doing does not necessarily correspond with the perceived movement (Jola, 2007). Thus, the researcher as the choreographer in one person may lead to confusion in the roles, probably comparable to the challenge of introspection in research a solo performer who is also the choreographer. There is no discourse on this issue, which I experienced as the main contest in merging science and performance. One of these examples is the performance "Aahh. .".

"Aahh. ." is a solo with three projections that interrogates common practices of performance. The performance consists of a live performer and projected recordings showing the performer from different perspectives. The question that stood at the beginning of the project was: How do we build a three-dimensional representation of a performer in our mind? Scientific knowledge of body perception and our sensory system informed the piece. Thus, the starting point for "Aahh. ." was twofold: first, my scientific research showed that we perceive other bodies in relation to their orientation in space. Second, our own bodily perception via the senses of touch, proprioception and vision is strongly modified by points of reference. The former defined the presentation via projectors and the latter was used in dance improvisation to create movements as well as to give the opportunity to observe changes between the reference points and the sensory modes. I called these changes switches between opposing directions in the senses and in the perspective.

Several dancers improvised to instructions based on sensory images (e.g., "imagine you are touching" versus "imagine you are being touched"). Thereby, I noticed that most dancers show an affinity for authenticity in one of the sensory modes. After a selection of the most authentically perceived movements, we noticed the importance of the performer's gaze. The dancer switches between different states of sensory awareness, and her modes of presence play with the audience's perception between private interrogation and objective distraction. The aim was to observe the spectators' re-orientation between the different projections and the dancer to allow inferences on body

Figure 10.3 "Ric and Elsa", Street Performance at Deptford X arts festival in Deptford, London, October 2008. Dancers: Riccardo Buscarini and Elsa Petit. Choreography: Corinne Jola. Picture by Maxwell ©. Supported by Deptford X.

perception and attention. I was interested in the audience's behaviour during these switches. Are there gaps of attention, where the spectator will re-orient his gaze? The work instills the importance of research as the core of choreography. The structure of the performance is semi-improvised. While the movements had an appealing aesthetics that emerged via the interrogation, the other strands of the performance appeared imposed. This probably happened at the moment when myself and the scenographer were too concerned about how to fit the aesthetics with the project's aims. Also the composition of the projections, which was organized in accordance with Baddeley's model of the working memory (Baddeley & Hitch, 1974), did not increase the value of the dance piece. Yet, when I used the movement material in a very different setting while ignoring any scientific investigation, the spectators reported huge aesthetic pleasure (see Figure 10.3; "Ric and Elsa", at Deptford X). Yet, I am therefore left wondering whether it is a necessity to give up the aim of scientific investigation to be able to make work that is artistically recognized.

Nevertheless, the movements of "Aahh. ." are still used for illustration purposes. For example, our preliminary results from the kinesthetic empathy project showed increased alertness of the spectators' motor cortex in both

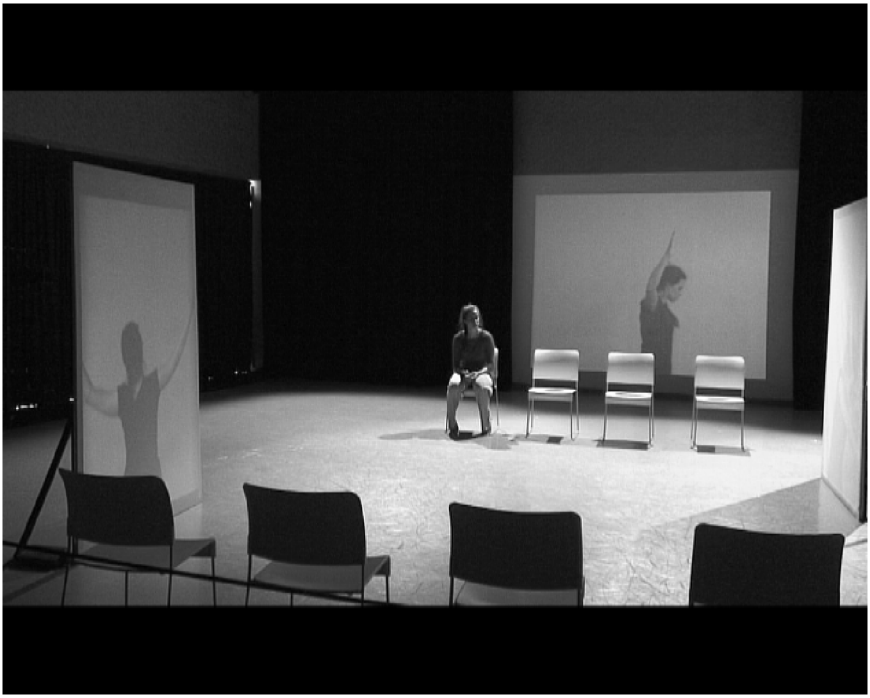

Figure 10.4 "Aahh. ." Performance at Laban Studio Theatre, London, May 2008. Dancer: Natascha Ruegg. Choreography: Corinne Jola. Picture by Erik Havadi ©. Supported by Rebekka Skelton Fund.

dance types, Bharatanatyam and classical ballet, when the performer was looking at them. To illustrate effects of the dancer's gaze we performed the movements of "Aahh. ." after a talk at the Laban conference in London in 2008. Importantly, the audience's experience and feedback also brought new ways of looking at our data. While we would interpret the increased response as an increased engagement, the audience's feedback points in the opposite direction, namely, that they felt taken back (see Figure 10.4).

Finally, I would like to give an example of how dancers can use the knowledge of cognitive neuroscience to find a way of expressing the choreographers' ideas. It is also an example which shows that it is not necessary to measure the effect when we can experience it at a phenomenological level – unless we want to understand the underlying neural processes and networks involved in voluntary movement and consciousness.

In "The Glories of Endurance" (see Figure 10.5), the performers had to change direction from lying down to getting up at the very last moment. My dancers found it very difficult, they either moved too early or too late. The aim was to get up as soon as they reached maximum relaxation, but not before. I then talked about voluntary movements, and explained how the motor command from the brain to the muscle (efferent signal) takes time to travel to execute the actual movement, and how the brain receives feedback from the muscles (afferent signals). I told my dancers that, by the time the brain receives the information that the hand is relaxed, they have already

Figure 10.5 "The Glories of Endurance". Performance at Bonnie Bird Theatre, London, October 2008. Performers: Natascha Ruegg, Riccardo Buscarini, Ulla Moeckel. Choreography: Corinne Jola. Picture by Alicia Clarke ©.

received the action potential to get up. Thus, they should imagine sending the command to move shortly before they actually relax, so that by the time the action potential has arrived at the muscles, the body is actually relaxed. This explanation of motor commands, feedback and the timing of the afferent and efferent signals helped the dancers in their expression. After my instruction they were finally able to move at exactly the right time. Why is it that the dancers were able to perform this with the right timing even though one must assume that they do not have conscious access to the motor command or its timing? Firstly, this is a subjective, uncontrolled experience. Second, I do not assume that this gives any direct insight in the understanding of motor control. I assume that the dancers created a neutral image which increased their awareness for the movements. For a valid explanatory model, however, we could design an experiment not only for testing in the laboratory, but as an element of the performance, such as playing with intention imagination versus emphasis on the movement form in choreography. Then I would speak of experimental choreography. It would give the audience an experience in watching effects of consciousness and presence on stage, phenomena that are currently of great interest in dance and neuroscience.

Summary

Humans have always been fascinated by the invisible. This innate interest in the unknown is the basis for the development of both art and science. Until a particular point in history, these two disciplines were regarded as one before they separated. Aesthetic properties of objects are most important for the arts, while science emphasizes objectivism. We cross the border between art and science with projects that demonstrate exemplary interdisciplinary approaches. In this chapter, I have only given a few examples that are at different stages of combining dance and cognitive neuroscience. I hope that my previous attempts at contrasting research and practice within both fields and where dance meets neuroscience will lead to new exciting experiments and provoke ideas in experimental choreography. However, we are still very close to the starting point.

In this chapter, I started with an introduction to the term "experimental choreography", describing a form of how dance work may be designed to investigate human perception, cognition and behaviour. In the last paragraph, however, I suggested that present research in cognitive neuroscience aiming to approach dance in the natural environment should use the method of observation by neurophysiological technologies. At the moment, these two directions are opposing. While dance may experiment with rigid empirical designs, neuroscience looks back to the possibilities of respecting subjective observation. On the one hand, experimental design is pursued, while on the other hand observational practice is emphasized. If we respect an itinerary process of dance and cognitive neuroscience, they will merge eventually. In other words, this is probably the first round of many we hope will follow.

The research described in this chapter is primarily on expertise effects. Up until today, the number of scientific investigations I am referring to is bigger, with more academic papers than other forms of dissemination. However, notably, expertise plays an interesting role in current dance works. For instance, conceptual dance is trying to challenge the experienced audience members' expectations of what dance or a performing body is. Another important aspect is to improve dance training methods based on scientific research. Elements of teaching have mostly evolved from practice, but not only. A huge interest exists in developing training methods to increase the dancers' health (e.g., Dance Science, Laban Trinity College London). Scientific research is important and can lead to a more profound understanding of factors affecting the dancers' well-being. However, imaging methods from neuroscience are dispensable when questions can be answered without the proof of change in brain activity. For example, when a training method is successful, an increase in the level of the students' performance can be observed or a decrease in injuries measured. Thus, practice and experience can show whether a method of teaching and learning is effective. Brain imaging methods are useful to study changes in brain functions for scientific purposes, such as to indicate neuronal plasticity, cognitive and behavioural factors, and emotional and expressive processes to understand human interaction and communication.

Finally, science and art have major diverging paradigms. In science, objectivity and reliability are two main criteria. In dance performance, the subjective experience of the spectator is prevalent. My interest and aesthetic appreciation of the bridge between the two is evident. My main aim in dance is to pursue an itinerary process as in science: I do not "create" an outcome; I do investigate something. Science investigates the invisible. Art makes us experience it.

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