Chapter 1

Introduction
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1.1 Brain and Body

Why has evolution equipped us with a brain? What is the purpose of our cognitive system? When trying to answer these questions, it might be interesting to have a closer look at species in nature which have developed brains or brain-like structures and compare their capabilities with existing organisms which have no brains. In doing so, it becomes immediately obvious that all species that can perform any kind of movement or action such as insects, fishes or mammals have at least a rudimentary brain, while biological organisms that cannot act, re-act or move, like for example trees or corals, have no functioning brain-like structure. An illustrative example in this context is the ontogenetic development of sea squirts. At the beginning of their lives, sea squirts are able to swim. They have a simplified central nervous system consisting of a cerebral ganglion that controls movements. In other words, sea squirts have simple brains. At a certain point of time, however, when the animal finds a suitable place to stay, it stops swimming, attaches itself to a permanent object on the sea ground and does not move anymore. Interestingly, after settling down, the nervous system previously used to control movements breaks down immediately and the sea squirt starts digesting its own brain. Apparently, without the requirement to move, there is not need for having a brain. One might therefore provocatively hypothesize that the basic function of the brain is to control motor behavior, or from a psychological perspective, that the purpose of cognition system is to serve actions.

Certainly, the example of the degradation of the sea squirts’ nervous system is merely just an anecdote and does not represent any scientific argument for the importance of actions in human information processing. Nevertheless, many theorists in the last decades have proposed action-oriented views on cognition, which share the basic assumption that the central function of the mind is to guide actions (for a recent review see, e.g., Wilson, 2002). For example, Churchland, Ramachandran, and Sejnowski (1994) mention that “vision has its evolutionary rationale rooted in improved motor control” (p. 25). Glenberg (1997) argue similarly and emphasize that “memory evolved in service of perception and action in a three-dimensional environment” (p. 1). Moreover, Clark (1998) even states that the traditional distinction between perception, cognition and action may sometimes obscure our view for a better understanding of the cognitive processes and functions. He proposes conceptualizing cognitions as body-related processes, because “the brain is revealed not as (primarily) the engine of reason or quiet deliberation, but as the organ of environment-situated control. Action, not truth and deductive inference, are the key organizing concepts.” (p. 268) Following this embodied view on human information processing, each cognitive mechanism has to be considered in terms of its function in serving adaptive behavior and its contribution to control motor behavior.
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However, a glimpse inside almost every available cognitive psychology textbook reveals that most information-processing theories are still dominated by the traditional assumption that perception, cognition, and action are three independent stages in a serial chain of processes (see Donders, 1886; Sternberg, 1996). In these classical approaches, actions are implicitly conceived as a mere consequence of information processing, that is, as stimulus-induced re-actions or as “trivial appendages to the seemingly more sophisticated operations subserving ‘higher-level’ cognition” (Fischer & Zwaan, in press). Researchers in this tradition have consequently put much more emphasis on the receptive than on the productive side of human behavior and aimed in their empirical work to reduce movement-related processes as far as possible (e.g., by using simple button press response tasks) in order to isolate them from processes of perception and cognition. However, the strict separation of motor action from perception and cognition does not adequately capture the goal-directed nature of human information processing and intentional behavior (Hommel, 2005; see also Rosenthal, 1983, and Abrams & Balota, 1992, for earlier critiques of this approach). The new generation of cognitive scientists should therefore focus, as for example suggested by Lakoff & Johnson (1999), on approaches of embodiment and the close interaction between mind and body and between cognition and action (cf. Garbarini & Adenzato, 2004).

In the following I will describe four influential theoretical concepts—the ideomotor principle, the common coding principle, the principle of motor simulation and the principle of motor resonance—which have inspired in recent years many empirical studies and which all suggest a strong coupling between perception and action on the one hand and between cognition and action on the other.

1.2 Perception and Action

1.2.1 Principle of Ideomotor Action

The notion that action and perception are mutually dependent processes is not new and dates back to the early days of experimental psychology. Theorists at the end of the 19th century searched for an answer to the question how voluntary actions are possible at all and proposed the so-called ideomotor principle, which basically holds that actions are represented in terms of their sensory effects in the environment. According to this assumption, human actions are initiated by nothing other than the idea of the sensorial consequences that typically result from them. Merely thinking about an action and its intended consequences prompts and instigates a motor response. Thus, the central mechanism underlying the planning of actions is an anticipation of their perceptual effects. The principle of ideomotor actions has been most dominantly proposed by James
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(1890), whose considerations were strongly influenced by the British and German psychologists Carpenter (1852) and Lotze (1852; for an overview of the historical roots of ideomotor theories see Stock & Stock, 2004). According to James, learning is a precondition for the control of voluntary actions. Since every performed movement goes along with a perceivable change in the environment, the actual motor action and the sensory consequences become associated. Once the bidirectional connection between action and consequences is established, the motor response can be initiated by the mere activation of the intended action effect in the mind (i.e., “Vorstellung des Gewollten”; Lotze, 1852).

The ideomotor theory as it was originally formulated by James represents a purely introspective approach. Almost a century later, however, Greenwald (1970a) provided an extension of these considerations, which allows empirical and experimental validations. He hypothesized that if responses are coded by representations of their sensory feedback, it implies that the perception of a stimulus, which closely resembles the consequences of a previously learned action, should result in a priming of this particular motor response. And in fact, Greenwald (1970b) demonstrated that stimuli representing well-known action effects primed responses that typically produce them. For example, verbal responses were found to be faster to auditory stimuli than to visual stimuli, because speaking produces auditory but not visual effects. Several studies have investigated since then effects of ideomotor compatibility and demonstrated experimental evidence for an influence of anticipated or perceived action effects on motor response (e.g., Stürmer, Aschersleben, & Prinz; 2000; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Kunde, 2001; Elsner & Hommel, 2001; Koch & Kunde, 2002; Drost, Rieger, Brass, Gunter, & Prinz, 2005). For example, Brass et al. (2000) demonstrated that the observation of a finger-lifting movement facilitates the equivalent finger movement even in a simple response task. Interestingly, Elsner & Hommel (2001) demonstrated that associations between actions and their effects are automatically and incidentally learned. Participants experienced, in an initial learning phase, the co-occurrences between left and right keypress responses and low- and high-pitched tones, and subsequently made keypress responses in a free- or forced-choice paradigm. As the reaction times indicate, the presentation of tones facilitates the execution of left or right key presses, depending on the previously acquired response-stimulus association. Thus, research in the last decades has accumulated empirical support for the ideomotor hypothesis and demonstrated that participants use automatically acquired associations between motor responses and perceived consequences for the planning and initiation of actions.

The notion that the voluntary control of actions involves an anticipation of intended effects implies that action planning is seen as goal-driven process—a central assumption that can be also found in some theories of motor control (e.g., Jeannerod, 1997; Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001; Glover;
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2004) and imitation (e.g., Bekkering, & Wohlschlager, 2002). Anticipatory action control implies furthermore that action and perception are two functionally linked cognitive processes. This notion has been adopted in particular by the framework of common coding (Prinz, 1990; Hommel, Müsseler, Aschersleben, & Prinz, 2001), which tried to integrate the ideomotor principle with concepts and ideas of modern cognitive psychology. The next section will therefore describe the common coding principle in greater detail.

1.2.2 Principle of Common Coding

Prinz (1990; 1997) suggested a common coding theory, which aimed at understanding the linkages between the “late” products of perceptual processing and the “early” cognitive antecedents of motor actions. The central assumption of this model is that perception and action share and operate on common cognitive codes within one representational domain. The common coding principle has been recently elaborated in greater detail by the Theory of Event Coding (TEC; Hommel et al. 2001). The model holds that perceived and to-be produced events, such as intentional actions, are represented by a network of linked codes of relevant features of the event (the so called ‘event file’). Thus, in line with many theories on perception, attention, and memory (e.g., Allport, 1987; Singer, 1994, Kahneman, Treisman, & Gibbs, 1992, Treisman, 1996), it is assumed that stimulus representations are feature-based. However, since perception and action are entirely commensurate, TEC states furthermore that also action plans are represented in a distributed fashion and comprise in the same way temporary composites of cognitive codes (i.e., action-feature codes).

Evidence for a feature-based action representation can be found, for instance, in classical motor control experiments showing that movement initiation times decrease if subjects have the opportunity to partially make up their action plan in advance (Rosenbaum, 1980, 1987). In these experiments, participants were required to perform speeded hand movements consisting of different action features (e.g., with the left or right hand, for a short or long distance, toward or away from the body). Movement precues were presented before the actual go signal and informed about some or all response parameters. As the response latencies indicated, movements were faster initiated with an increasing number of precued action features, suggesting that subjects are able to specify the features of their action relatively independently.

Importantly, according to TEC, the common representation of perception and action is characterized by a distal coding of event features. That is, feature codes of perceptual objects and action plans refer to external, that is, distal features of stimuli or action-generated effects. The model shares this notion with other approaches to action planning assuming that movement planning is goal-directed and guided by the desired movement end-states (Rosenbaum
et al., 2001). However, in contrast to these approaches, TEC holds that motor behavior is not only guided by proximal action effects such as proprioceptive and visual feedback of a performed movement. Rather, the common coding principle suggests that action-generated effects refer to the highest level of representation and to the remote consequences that the action is supposed to have on the environment. For example, if one intends to decrease the volume of the music by turning a knob of the stereo amplifier, the cognitive representation of the planned action does not refer merely to the muscle contractions or visual feedback of the rotational movement, but involves instead the actual intended effect in the environment, namely, the change of volume. From a theoretical point of view, the crucial advantage of a distal reference system is that perception and action can operate on commensurate representations. This does not only simplify many cognitive processes, like for example the transformation of visual object properties (e.g., object size) into appropriated motor commands (e.g., grip aperture) as required while grasping, it also enables the cognitive system to abstract from domain- and modality-specific coding characteristics by referring to the informational content of the action or event (Prinz, 1997). The idea of distal coding of event features is supported by numerous reports in the literature on both perception and action planning (for a review see Hommel et al., 2001) and also receives evidence from research on ideomotor actions (see above). As one recent example, Rieger (2004, 2007) compared participants who were able to type fluently using the 10-finger-system with participants doing hunt-and-peck typing with two fingers only. She found that expert typists had built up an integral representation of fingers movements and the corresponding letters, resulting in an automatic bidirectional association between motor responses and distal action effects.

Taken together, the common coding principle holds that representations of perceived events as well as representations of actions and action-generated effects are based on the same cognitive codes referring to distal event features. In this way, perception and action planning can be understood to be functionally equivalent, because, as argued by Hommel et al. (2001), “they are merely alternative ways of doing the same thing: internally representing external events” (pp. 860).

1.3 Cognition and Action

The notion that perception and action operate on shared representations raises the question whether the common coding principle is restricted to the perceptual domain. Alternatively, it might be possible that the close bidirectional coupling of mental representations with motor codes is a generalized principle of how the brain processes and represents information. Indeed, research in the field of
neuroscience and cognitive psychology has recently indicated that motor representations are involved in a wide range of cognitive tasks and contribute even to rather complex processes such as the understanding of other’s actions (Wilson & Knoblich, 2005), the processing of language (Glenberg, 1997) and numerical information (Walsh, 2003). This section will elaborate these ideas in the light of two further coding principles emphasizing the role of action in cognition.

1.3.1 Principle of Action Simulation

Many studies in animal research and cognitive social psychology have suggested that motor processes are strongly involved in understanding the behavior of conspecifics (Wilson & Knoblich, 2005; Prinz, 1997; Rizzolatti & Craighero, 2004). The rationale behind these models can be summarized by the principle of action simulation: People, who observe somebody else performing an action, activate the same neural substrates that are recruited when they performed that action themselves. In other words, action understanding implies an internal, covered imitation of the observed motor behavior.

Action simulation received recently a lot of attention due to the discovery of the so called mirror neurons in macaque monkeys, which are sensitive to action execution as well as action observation (Gallese, Fadiga, Foggassi, & Rizzolatti, 1996; for review, see Rizzolatti & Craighero, 2004). That is, single-cell recordings in monkeys’ premotor cortex (in particular area F5) revealed that this type of neurons increase their firing when the monkey performed an action (e.g., grasping a food item) as well as when it observes an experimenter or conspecific performing a similar action. Importantly, it could be shown that the mirror system is responsive to the understanding of the action goal and not merely to the perception of the motor movement. Specifically, the monkey mirror neuron system was shown to respond to goal-directed grasping movements, even if the final goal (food) was occluded (Umiltà, Kohler, Gallese, Foggasi, Fadiga, Keysers, & Rizzolatti, 2001). As shown by a large number of neuroimaging studies, a mirror-neuron system similar to that of the monkey likely also exists in humans (Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999; Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese et al., 2001; Decety, Chaminade, Grezes, Meltzoff, 2002). This research demonstrates that the observation of actions performed by others activates a complex network including the Broca’s area, an inferior frontal brain area considered to be homologous to area F5 in the macaque monkey, and other cortical regions whose functions are predominantly motor related (cf. Rizzolatti & Craighero, 2004).

The notion of action simulation implies furthermore that the observation and understanding of other’s actions involves previously acquired motor experiences. In line with this reasoning, it has been shown the activation of the human mirror system strongly depends on motor knowledge and expertise. For ex-
ample, Calvo-Merino, Glaser, Grèzes, Passingham and Haggard (2005) studied experts in either classical ballet or capoeira dancing (i.e., a Brazilian fight-dance) and found greater activity in the premotor and parietal brain regions when dancers watched their own dance style. A follow-up study (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2006) ruled out that the differences in motor activation were not merely the result of visual familiarity. It can be thus concluded that the motor system is more strongly engaged during action understanding when participants have a specific motor representation of the behavior they observe.

In addition to this neuropsychological work, the idea of action simulation receives support from behavioral studies. The above described finding of ideomotor compatibility effects during action observation (Brass et al. 2000; Stürmer et al. 2000) is just one example. Kilner, Paulignan, & Blakemore (2003) provide further evidence by showing that people’s attempts to perform an arm movement become more variable when watching an incompatible arm movement. Similarly, interference effects of action simulation have been found during the observation of mouth movements. People are faster to pronounce a printed syllable when they see a mouth pronouncing the same syllable than when they see a mouth pronouncing a different syllable (Kerzel & Bekkering, 2000).

In sum, empirical research shows that the observation of body movements automatically triggers a sort of covert imitation resulting in an activation of motor-related brain areas and a facilitated execution of similar motor responses. These findings suggest that action simulation is a cognitive principle subserving the conceptual understanding of other’s behavior. Action simulation reflects thus another example for the involvement of motor representations in cognitive processing.

1.3.2 Principle of Motor Resonance

The important role of motor representations as it has been described above clearly points to an embodied information processing approach in perception and action understanding. This raises the general question whether embodiment can be understood as a universal coding principle also valid for high-level cognitive processes such as the word reading and the coding of abstract semantic information. Some recent studies on grasping actions provide evidence for this notion and showed that semantic information effect the planning of actions. Gentilucci, Benuzzi, Bertolani, Daprati, and Gangitano (2000) reported, for instance, that reach-to-grasp movements are influenced by the semantic properties of distracting words. They showed that Italian words denoting far and near reprinted on to-be-grasped objects had comparable effects on movement kinematics as actual greater or shorter distances between hand position and object. Automatic word reading effects have also been observed for words im-
plying explicitly or implicitly size-related semantic information. For example, the maximum grip aperture during reaching has been found to be enlarged after reading the word *large* as compared to the word *small* (Gentilucci & Gangitano, 1998; Glover & Dixon, 2002) or after reading the word *apple* as compared to the word *grape* (Glover, Rosenbaum, Graham, & Dixon, 2004).

Beside this work on motor control, also theoretical work on language comprehension has recently highlighted the role of motor information in high-level cognitive processing (e.g., Lakoff & Johnson, 1999, Glenberg, 1997; Clark, 1998; Gallese & Goldman, 1998). These approaches are motivated by the problem of symbol grounding—a problem that is faced by each theory on semantic knowledge and that represents the basic question of how linguistic symbols such as words, numbers, or syntactic constructions acquire meaning. Although embodied approaches to cognition differ widely on the emphasis that is put on separate cognitive subsystems and on the way in which conceptual knowledge is organized (for recent overviews see Fischer & Zwaan, in press; van Elk, van Schie, Linde mann & Bekkering, in press; Barsalou, in press), they all share the assumption that symbols can become meaningful only when they are somehow mapped to non-linguistic perceptual experiences and bodily activities. The cognitive system operates accordingly on representations that are grounded in perception and action, or in other words, cognition is based on embodied knowledge. Following this line of reasoning, theories of semantic representations have been proposed, which relate abstract concepts to perceptual experiences (Barsalou, 1999) and motor actions (Glenberg, 1997; Zwaan, 2004). Sharing the assumption that the comprehension of meaning is a fundamentally body-related process that involves sensorimotor representations, these models predict that the processing of linguistic stimuli causes a reactivation of perceptual and motoric representations of the objects and actions that underlie this abstract semantic information. This automatic activation of embodied representations represents a form of mental resonances (cf. Zwaan, 2006), which can be subdivided according its modality into perceptual resonance and motor resonance (see Schütz-Bosbach & Prinz, 2007, for this distinction in the context of social cognition).

Perceptual resonance refers to sensory activation due to mental imagination. Evidence for this phenomenon is provided by several behavioral experiments on sentence comprehension (Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yax ley, 2002; Pecher, Zeelenberg, & Barsalou, 2003; Kaschak, Madden, Therriault, Yaxley, Aveyard, Blanchard & Zwaan, 2005). For example, Stanfield and Zwaan (2001) required participants to verify that a picture (e.g., a pencil) depicted an object mentioned in a sentence (e.g., “The pencil is in a cup”). They observed faster responses if the object on the picture was presented in the same orientation as implied by the sentence (in this case a vertically depicted pencil). Thus, understanding the sentence appears to call on real perceptual experience.
1.4 Summary and Aims

The notion of motor resonance refers to motor activation in semantic processing due to mental simulation or re-enactment (cf. Prinz, 2006). This coding principle represents therefore the most straightforward conceptualization of the coupling of action and high-level cognition as it is in the focus of the present thesis. Importantly, the concept of motor resonance goes far beyond the phenomenon of action simulation, because it does not reflect merely the matching of perceived actions with existing motor repertoire. Rather, motor resonance stands for a coding principle to deal with semantic knowledge on an abstract level of representation and is expected to cause therefore interference also when processing symbolic information. Evidence for this idea comes from neuroimaging studies showing that reading of action words activates motor-related brain areas (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Hauk, Nikulin, & Ilmoniemi; 2005; Rüschemeyer, Brass, & Friederici, 2007) as well as from behavioral research demonstrating the presence of priming effects on motor responses while sentence comprehension (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006; Borreggine & Kaschak, 2006; Taylor, Lev-Ari, Zwaan, in press). For example, Glenberg and Kaschak (2002) found that sentences describing simple motor actions facilitate the execution of compatible motor responses (i.e., Action Sentence Compatibility effect). They asked participants to judge the sensibility of sentences such as “You gave Andy the pizza” or “Andy gave you the pizza” by moving the hand from a start button to the Yes button. The location of the buttons required a literal movement either toward the body or away from the body. Participants were faster to execute the motor responses when the direction of the response matched the direction of the motion described by the sentence (e.g., making a response towards the body to the sentence “Andy gave you the pizza”).

1.4 Summary and Aims

Taken together, psychological research offers several ideas and theoretical concepts that suggest that motor representations are involved in different cognitive functions ranging from low-level cognitive processing such as visual perception up to high-level cognitive processing such as language processing. Surely, the four principles of embodied cognitive processing described above—the ideomotor action principle, the common coding principle, the action simulation principle and the motor resonance principle—represent only a selection of views on action-perception and action-cognition coupling among many others in the literature. They also should not be understood a four disjunctive independent concepts, since they are interrelated and to some extent even mutually conditional. For example, action simulation can be conceptualized as a special case of motor resonance, the common coding principle implies the principle of ideomotor actions.
and the notion of motor resonance can be derived following a few assumptions from the Theory of Event Coding.

As described above there are ample studies providing support for the interference effects between action and cognition in different domains. However, it is still unclear to what extent action intentions affect cognitive coding and whether there are any limits of motor involvement in information processing. One might therefore assume that embodiment and the involvement of motor representations is a generalized universal coding principle, which applies in theory to all cognitive processes and to the coding of all types of information. Guided by this hypothesis, the present thesis sought for evidence of motor effects in a wide range of cognitive domains and aimed to address within this context some open questions. The following chapters therefore investigated action effects in the domain of visual processing (Chapter 2), word reading (Chapter 3) and number processing (Chapters 4 & 5).

Since most of the research on action effects has focused on rather simple one-dimensional actions like button press responses or bare grasping movements, a specific aim of this thesis was to explore whether motor interference effects can be also observed for more complex natural actions, which are directed on a specific goal and which consist of more than just a single movement. The first three chapters investigated effects of object manipulations such as the grasping and turning of an object and the use of a familiar tool. In particular with respect to the idea that actions are goal-directed and represented by their intended distal effects (cf. ideomotor and common coding principle), it is interesting to explore the role of actions goals that are on a higher level in the hierarchy of possible subgoals. The thesis intends therefore to shed some light on the impact of motor features that occur at the end of complex motor sequences, like for instance the intended manipulation after grasping an object or the goal location of the use of an object. At the end of this introduction I present a short overview of the empirical work in the following four chapters.

1.4.1 Action and Visual Processing

Chapter 2 focuses on the coupling between perception and the preparation of natural grasping actions. In three experiments, we established an experimental paradigm, which allows to investigate cognitive interference effects in the context of object manipulations and which can be later utilized to study effects on other cognitive processes. We assumed that the intention and preparation to manipulate an object affects visual processing. Since each object manipulation results in a perceivable motion as an action consequence, Chapter 2 aimed in particular to find evidence for action-induced effect on motion perception.
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1.4.2 Action and Semantic Processing

Chapter 3 aimed to provide support for the notion that effects of motor preparation are not restricted to the visual domain. The major question to be addressed was whether the planning of goal-directed actions interferes with the language-related processes. We conducted therefore four experiments, which examined the impact on the preparation to reach out, grasp and use a meaningful object (i.e., household tool) on the processing on semantic information in different word reading tasks (e.g., lexical decision task and semantic categorization task).

1.4.3 Action and Number Processing

Chapter 4 aimed to further support the notion of embodiment as a generalized coding principle and sought for evidence for motor involvement in a high-level cognitive domain that has not been studied so far. A promising candidate is the domain of mathematical cognition, because the coding of numbers and the planning of motor responses (e.g., object grasping) are two cognitive tasks, which both depend essentially on the same type of information, namely, an accurate knowledge about size and quantity. In line with this consideration, a study on the interference between grasping actions and number processing was conducted, in which participants judged the parity of presented digits and indicated their decisions by performing either a power or precision grip action.

1.4.4 Intention and Number Processing

Chapter 5 further investigates the representation of numbers and addresses the phenomenon of the interaction between numerical magnitude information and lateralized motor responses (i.e., the SNARC effect). Again, we aimed to investigate the impact of intentions on cognitive processes. With this study, however, the focus of attention is shifted from the effects of motor intentions to the effects of coding intentions and cognitive strategies. Two experiments are reported, which examined whether number representations are influenced by implicit task requirements in order to test the hypothesis that coding strategies are responsible for the cognitive coupling between numbers and spatial response features.
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