0. Overview

The subject of this thesis are the processes that underlie our awareness of intentional actions. In a series of experiments, the subjective onset time of a movement was measured and compared to the physical occurrence of the movement. In previous studies, the subjective onset time of intentional movements was shifted towards a tone subsequent to the movement. This attraction was termed temporal binding. It has already been argued that temporal binding associates movements and effects in awareness. Thereby, temporal binding may facilitate the representation of one's own and other's intentional actions. The experiments in this thesis explored temporal binding and its contribution to the awareness of intentional actions. Three questions have been addressed:

First, it was questioned whether or not temporal binding indicated the integration of a distal event into the representation of a movement. Second, the necessary and sufficient conditions for temporal binding have been explored. Specifically, it was asked how temporal binding was influenced by implicit and explicit attributions of intentions. Third, the experiments explored whether the actual occurrence of a physical effect was necessary for temporal binding.

This thesis is organised as follows: The introduction will set the theoretical framework and highlight relevant ideas concerning the planning, execution and awareness of human action. Thereafter, the concept of temporal binding will be introduced, including a review of the relevant research and a specification of the research questions. The central part will describe seven experiments, their results and their implications for the concept of temporal binding. The third part will start with a summary of the results and a discussion of selected aspects. Moreover, an overall picture of temporal binding and of its functional role for the awareness of intentional action will be developed.

1. Introduction

1.1 Human action

Even though psychology as a scientific subject is relatively young, the reasoning about how and why people act does have a long tradition. For instance, the French philosopher René Descartes strongly influenced how psychologists thought about human action. Descartes (1664) postulated a substance dualism between the mind (res cogitans) and the body (res extensa). He argued that the mind, a thinking thing, can exist apart from the extended body and is therefore a substance distinct from the body (see also Cottingham, Stoothoff & Murdoch, 1984). As illustrated in Figure 1, Descartes understood actions primarily as movements of the body. Consequently, he did not describe actions in terms of the mind but as reactions to the sensory stimulation.

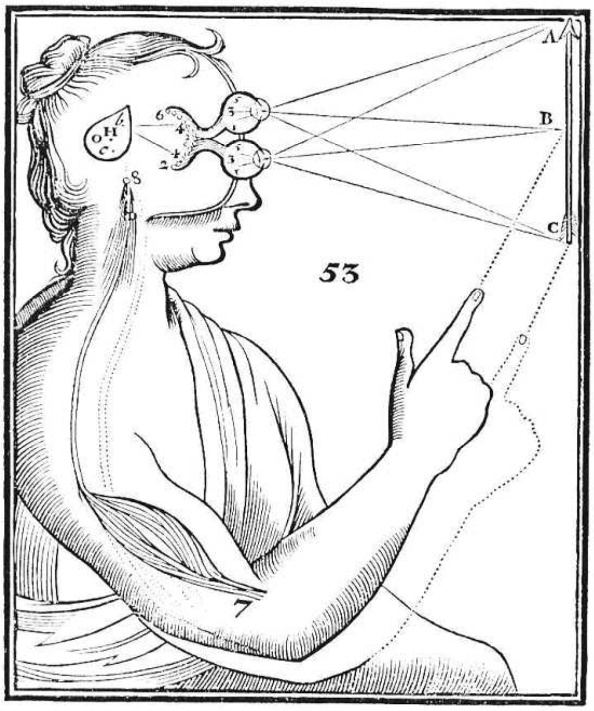

Figure 1: The Cartesian view of human action.

Figure 1 also shows the pineal gland, roughly in the “centre” of the brain. According to Descartes, the pineal gland is where sensory and motor processes meet. Moreover, through the pineal gland the mind is able to interfere with the otherwise mechanistic processes of the body. Although Figure 1 illustrates the connection of sensory and motor processes in a rather direct way, one could question whether Descartes really aimed to reduce actions to mere reactions to sensory stimulation. In contrast, the connection of sensory and motor processes in the pineal gland required, or at least allowed, an interaction with the mind. Nevertheless, Descartes’ mechanistic view laid the groundwork for a psychology that restricted the explanation of human actions to their sensory antecedents.

However, most people would claim that a description in solely reactive terms does not reflect the phenomenological experience associated with their actions. For instance, when I reach for a cup, one would argue that I simply do so because I intend to drink the coffee. Although this example does not rule out that my actions can be triggered by external stimuli, it clearly exceeds the concept described above: First, it includes the subjective experience accompanying an action: When acting, we do not only move our body but we are also aware of our intentions, movements and the environmental effects we cause. Second, the example puts into question whether movements are *always* triggered by external stimuli. In contrast, we usually assume that actions can also arise from the “subject within”. The difference becomes clear in Heckhausen (1991). In his book “Motivation and Action” he refers to the German sociologist Max Weber. The way Weber (1921) defined action clearly exceeded mere reactions in response to sensory stimulation:

> “According to Weber, action includes all human behaviour which has a “meaning” for the behaving individual. […] An action comprises all activities, which purpose the same “goal idea”. Whether the goal is conscious or unconscious, in both cases it is mentally represented.” (Heckhausen, 1991, p. 12).

While Weber (1921) applied this concept to the social interpretation of behaviour, the goal-directedness of a movement was also suggested to be crucial for its control. Ach (1910, p. 256) for instance argued that an action “represents the realization of the anticipated concrete content of an act of will” (translation in Hommel, 2003). Opposing the views of Descartes and Ach, it becomes clear that they approached human action from very different perspectives: Whereas Descartes focussed on the relation between external stimuli and motor reactions, Ach highlighted how the internal idea to act gives rise to an action. Prinz (2003) characterised these different perspectives as the sensorimotor versus ideomotor view of action. The following section will pick up this distinction and give a more detailed description of both views. Thereafter, two psychological theories of human action control will be reviewed: The common coding theory of Prinz (1990, 1997) and the theory of event coding by Hommel, Müsseler, Aschersleben & Prinz (2001). Extending the basic concepts of human action, these theories include aspects of both, the sensorimotor as well as of the ideomotor view.

1.1.1 The sensorimotor view

As mentioned in the previous section, the mechanistic view of Descartes laid the groundwork for a psychology that described actions in terms of their sensory antecedents. In other words, actions were seen as reflex-like pattern of movements that are elicited by sensory stimulation (cf. Shepherd, 1994 for a more detailed differentiation between reflexes and movement-pattern). The main success of this framework was the description of learning principles, that is, ways in which new relations between stimuli and reactions can be established. One of the first and probably the most famous was the salivation reflex in dogs, studied by Pavlov (1927). By introducing an association between the sound of a bell (neutral stimulus) and some food (termed unconditioned stimulus, since it evokes salivation in itself) he induced a salivation response to the sound of the bell alone (turning the neutral into a conditioned stimulus). A research tradition known as “behaviouristic psychology” extended these findings to human behaviour. Watson and Rayner (1920) for instance succeeded to induce a phobic reaction in the famous “little Albert” via a procedure similar to that used by Pavlov (1927), now known as classical conditioning. Even though one could question the behaviouristic concept of mental illness as a mere “habit distortion”, modern psychotherapy still relies on the learning mechanisms investigated in the high time of behaviourism (cf. Grawe, 1998).

Although the sensorimotor view quite successfully described how behaviour can be triggered and learned, its explanatory power was limited: It in principle neglected that actions also include a subjective experience. For instance, Watson and Rayner (1920) described emotional reactions in a purely behavioural way. They did not take into account that “little Albert” may have actually experienced pain or fear nor did they question whether Albert was aware of what he learned. By rejecting awareness and subjective processes, the behaviourist framework faced considerable difficulties dealing with pathologies regarding the awareness of actions such as psychotic symptoms in schizophrenia (cf. Frith, 1992). Nowadays, the awareness of actions has become a subject of its own right in scientific psychology. In fact, this thesis explores a particular process underlying the awareness of intentional action.

Another limitation of the sensorimotor view was its restriction to settings of well-defined stimuli and responses. Thereby, it could not account for situations where these relations cannot be specified. A third critic of the sensorimotor view refers to a theoretical level. Although the sensorimotor view focused on the relation between sensory and motor processes, it did not specify how sensory input can be related to motor output. Because input (e.g. pattern of visual stimulation) and output (e.g., motor efferences) are distinct by nature, their internal codes cannot be directly matched (Sternberg, 1969; Sanders 1980, 1983). In other words, the sensorimotor view described and explained empirical relations between stimuli and reactions, without specifying how these entities can be mutually linked (Prinz, 1990, 1997).

1.1.2 The ideomotor view

According to the sensorimotor view, actions are triggered by some kind of sensory stimulation. In contrast, the ideomotor view postulated that actions are triggered by the intention to act. In other words, the ideomotor view explained actions as means to achieve intended goals and not as reactions to sensory stimulation. Within the ideomotor view, a movement was seen to arise from an internal idea of the movement, respective of its effects (cf. Lotze, 1852). James (1890) conceptualised the relation between anticipated and executed movements in his famous ideomotor principle: “Every representation of a movement awakens in some degree the actual movement which is its object.” (James, 1890, p. 1134).

Greenwald (1970) took up this idea and refined it in the theory of ideomotor action. He assumed that actions are represented in terms of their anticipated sensory effects and that these anticipations allow the initiation and selection of a movement (Greenwald, 1970, p. 91). This extends the ideomotor principle: According to Greenwald (1970), an action is not only triggered by its “internal idea” but also by the perception of an associated sensory stimulation. This indicates that an ideomotor view of action does not necessarily contradict the sensorimotor view. However, the ideomotor view questions whether actions can entirely and adequately be described in terms of stimuli and reaction (cf. Prinz, 2003).

The following example illustrates the difference between sensorimotor and ideomotor explanations by experiments investigating children’s ability to imitate. Imitation, which can be roughly defined as a matching between the movements of an actor and an observed person, seems to be an example of a sensory-motor translation par excellence. Following Meltzoff and Moore (1994), a supramodal system allows a direct matching between visual input and proprioceptive information related to the execution of the movement. However, as Wohlschläger, Gattis and Bekkering (2003a) pointed out, direct matching theories cannot account for a number of findings in human imitation behaviour. They conducted a series of experiments (see also Bekkering, Wohlschläger & Gattis, 2000), in which children were required to imitate a model that touched his right or left ear with either the right or the left hand (see Figure 2).

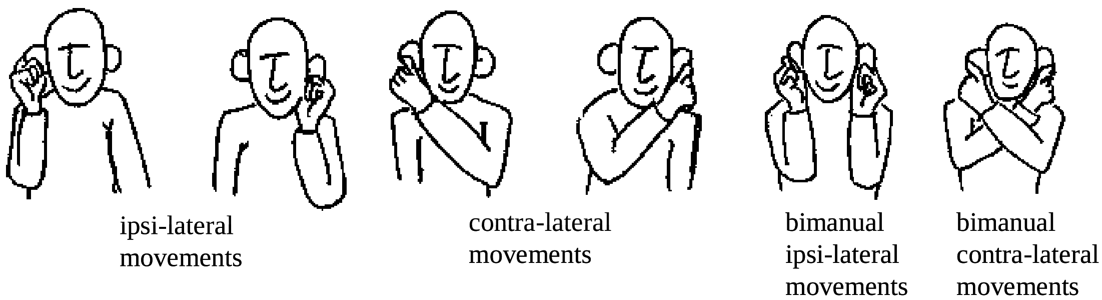

Figure 2: The hand gestures used in the experiments of Bekkering et al. (2000) and Wohlschläger et al. (2003a).

The results showed that the children almost always touched the correct ear. However, they tended to imitate both ipsi-lateral movements and contra-lateral movements with an ipsi-lateral response. This was not due to the avoidance of cross-lateral movements, because bimanual contra-lateral movements were imitated quite often, although they require a double-crossing of the midline. Wohlschläger et al. (2003a) suggested that direct sensorimotor translations cannot account for these results. Instead, they favoured an ideomotor explanation. They suggested that the representation of goals plays a substantial role in the observation and imitation of behaviour:

“ […] Imitation may be better explained in terms of goals and the intention to realise them. […] Children primarily imitate the goal of the model’s action while paying less attention to, or not caring about, the course of the movement.” (Wohlschläger et al., 2003a, p. 502).

Interestingly, ideomotor explanations are intuitively plausible because they reflect our subjective impression: When we act, we are rarely aware of the stimuli that triggered our behaviour or of the exact movements we produce. Similar to the children in the experiment of Wohlschläger et al. (2003a), we are mainly aware of the goals we intend to reach and the effects we aim to produce. Nevertheless, wee seem to be able to focus awareness on our movements, for instance when we are instructed to imitate the exact path of a movement. The crucial question, however, is what are we aware of in the latter case? Do we become aware of the movement itself and its kinematic properties? Or do we still become aware of the goals we aim to reach, this time at a more proximal level, that is, in terms of body movements?

Before addressing this question, it is necessary to go back to movement-control. The following section will review two theories that integrate sensorimotor and ideomotor concepts: The common coding theory of Prinz (1990, 1997) and, related to it, the theory of event coding (Hommel et al., 2001).

1.1.3 The common coding theory & The theory of event coding

In a nutshell, the common coding theory (Prinz 1990, 1997) focuses on a problem inherent in the sensorimotor view: The sensorimotor view highlighted the relation between sensory and motor processes because it explained actions in terms of sensory information. However, sensory information (e.g., pattern of visual stimulation) and motor information (e.g., motor efferences) are distinct by nature. Hence, their internal codes cannot be directly matched. In order to deal with this incommensurability, common coding refers to a shared representational domain that allows a matching between observed stimuli and to-be-produced movements. Extending this idea, Prinz (1997) argued that this commensurability is established on a sensory, rather than on a motor level. Besides a perception-related locus of the common code, Prinz argues

> ”[for a] correspondence between events and actions in distal, extracorporeal space and not [for] correspondence between stimulus and response pattern defined in coordinates of proximal body anatomy. […] Yet at a more abstract level of representation, the same two events may be commensurate, for instance, with respect to their […] semantic content (meaning or goal).” (Prinz, 2003, p. 173).

In other words, instead of postulating a translation, the common coding theory relates sensory and motor processes on an abstract level. This implies that on this level there is no principal difference between incoming (sensory) or outgoing (motor) signals within the cognitive system. Consequently, the theory of event coding (TEC) subsumes both as rather perceptual events: “[It postulates that] cognitive codes are always event codes of perceived or (to-be-) produced events.” (Hommel et al., 2001, p. 849). Moreover, at this point the rather sensorimotor concept of common coding is linked to the ideomotor principle: If there is no difference between sensory and motor events, then the imagination of a desired event (its sensory anticipation) will directly activate the movement leading to the anticipated event (Hommel et al., 2001). It is important to notice that, according to TEC, the cognitive code of an event refers to its distal properties rather than to proximal sensations such as proprioception. Hence, perception and action planning are both domain and modality unspecific. Instead, they do refer to an event’s informational content (cf. Prinz, 1992).

The association of an anticipated distal effect and a movement is crucial for ideomotor theories as well as for TEC. How does this association come about? Due to the variety of