Movements, actions and tool-use actions: an ideomotor approach to imitation

Cristina Massen* and Wolfgang Prinz

*Department of Psychology, Max-Planck-Institute for Human Cognitive and Brain Sciences,
Stephanstrasse 1a, 04103 Leipzig, Germany*

In this article we discuss both merits and limitations of the ideomotor approach to action control and action imitation. In the first part, we give a brief outline of ideomotor theory and its functional implications for imitation and related kinds of behaviours. In the subsequent sections, we summarize pertinent experimental studies on action imitation and action induction. These studies show that action perception modulates action planning in a number of ways, of which imitation is but one. In the last part, we move from regular actions to tool-use actions, raising the issue of whether and how watching others' tool-use actions leads to corresponding behaviours in observers. Here, we discuss experiments aimed at dissociating the relative roles of environmental targets, bodily movements and target-to-movement-mappings (action rules) in the observation of tool-use actions. Our findings indicate a strong role for action rules in the observation and imitation of tool-use actions. We argue that, in order to account for these findings, ideomotor theory needs to be extended to take mappings between bodily movements and environmental effects into account.

Keywords: ideomotor theory; action observation; imitation; tool use; motor resonance

1. INTRODUCTION

Any attempt to identify the cognitive and neural mechanisms of imitative behaviour in humans has to start with a broad idea of how human action generally comes about. In the literature, two theoretical frameworks addressing this issue can be distinguished. One is the sensorimotor approach, with its basic assumption that human action starts with environmental stimulation, which is then followed by a response from the organism. In other words, actions are consequences of stimuli that precede them. On the other hand, the ideomotor approach to human action proposes that actions are caused by intentions. These intentions arise in the individual and evoke suitable actions to realize them. In other words, actions are considered the means to realize certain ends that follow them.

While the sensorimotor approach to the study of human action has a much longer tradition in the behavioural and brain sciences, in this chapter we argue that the ideomotor framework offers a more suitable approach to explaining the mechanisms of imitative and related socially modulated behaviours. This is mainly owing to the fact that in the ideomotor framework, perception and action are not conceived of as being fundamentally different from one another as in the sensorimotor framework. Instead, they are viewed as highly similar in terms of their representational content. As similarity between what is being perceived and what is being done is also the defining feature of

imitative behaviour, there is a close conceptual link between ideomotor theory and any postulated mechanism of imitative and related behaviour.

In the following, we will first begin with outlining the major assumptions of ideomotor theory and their implications for imitative behaviour. These implications can be summarized in the principle of *action modulation through perception*. We then move on to discuss relevant empirical data on three increasingly complex types of motor behaviour (i.e. movements, goal-directed actions and tool-use actions) that have different implications for the ideomotor approach to imitation. With regard to methodology, the overview will introduce the different experimental paradigms (e.g. action imitation, action induction or action priming paradigms) that have been used to study this issue.

2. IDEOMOTOR THEORY AND THE PRINCIPLE OF ACTION MODULATION THROUGH PERCEPTION

As has already been stated in the introduction, one of the defining features of imitative behaviour is the similarity between the act perceived in the other and the act that is to be performed by oneself. This introduces a fundamental question that is also known as the correspondence problem (cf. Brass & Heyes 2005): how does the observer's motor system know which muscle activations will lead to the observed movement? As it is usually assumed that representational structures for perception consist of patterns of stimulation in sense organs and their derivates, whereas motor commands and patterns of muscle excitation correspond to representational structures on the action side, this question is difficult to answer. The ideomotor

framework offers a convenient approach to this question and to any explanation of imitational phenomena. This may not be immediately obvious because, in the beginning, ideomotor theory as put forth by Lotze (1852) and James (1890) was an account of how actions are guided by intentions, rather than by perceptions. According to Lotze and James, two preconditions are necessary for a voluntary action to take place. First, there has to be an idea or representation of what is being willed or intended (Lotze: *Vorstellung des Gewollten*), and second, conflicting ideas must be absent or have to be removed (Lotze: *Hinwegräumung aller Hemmungen*). If these two preconditions are fulfilled, the internal representations of what is intended have the power to evoke corresponding actions. 'Every representation of a movement awakens in some degree the actual movement which is its object; and awakens it in a maximum degree whenever it is not kept from doing so by an antagonistic representation present simultaneously in the mind' (James 1890, vol. II, p.526). This power of intentions to evoke associated motor responses is thought to arise from learning. Every time a motor response is executed, it leads to perceivable effects in the environment that can either be close to the action itself (e.g. kinaesthetic sensations) or quite remote from it, like for example, a light going on when the light switch is pressed. Once a connection between a certain motor act and its bodily or environmental effects has been learned, the internal representations of these effects can in turn elicit the actions with which they are associated. This principle applies both to the perceivable bodily effects of actions and to the more distal effects of these actions.

Starting from these early thoughts put forth by Lotze and James, the question may be raised of whether not only internal thoughts of movements or associated effects, but also their *perception*, in others for instance, may elicit corresponding action tendencies. Greenwald (1970, 1972) investigated this issue by having participants respond to certain stimuli that were the same as (or similar to) the feedback stimuli presented to these responses. For instance, a red-coloured stimulus could require a certain response that was then followed by a red feedback light. In this case, the red stimulus is similar to the effect produced by the required response and its perception can trigger the associated response in a very similar way to how might the internal thought of the red feedback light.

If the early ideomotor framework is extended to include perception as a triggering condition for actions, this approach can easily account for imitative behaviour: the perception of another's action or its remote effects can trigger the same action in the observer. This requires that the observer has previously learned the association between the action and its accompanying or remote effects. An important feature of this required learning mechanism between actions and associated effects is that it has to be bidirectional. Thus, learning an association between an action and its environmental effect entails learning the reverse association between the representation of the effect and its associated action (Elsner & Hommel 2001,

2004; Kunde 2001). Without this bidirectionality of learning, the representation or perception of action effects cannot trigger the action in the observer. Furthermore, the strength of the induced action tendency will depend on the degree of similarity between what is being perceived and what the individual has learned follows the action. This means that some kind of imitative behaviour, for example the 'opaque' movements occurring in facial imitation, are less easily explained by the ideomotor approach, because the sensory (visual) consequences of one's own facial expressions usually cannot be observed. In this case, additional assumptions have to be made concerning the way bidirectional associations between visual representations of actions and the corresponding somatosensory/motor representations can be acquired. A theory of imitation addressing this problem is the Associative Sequence Learning model (Heyes & Ray 2000).

The extended ideomotor framework also has a more general implication that refers to the functional architecture of action planning and action control. Because actions are represented through their perceivable effects, perceptual event representations and representations of actions are no longer entirely separate and incommensurate. Instead they develop, on top of and in addition to separate and incommensurate representations, representations in a joint domain that they both share and in which they both maintain commensurate entries. These entries are commensurate in the sense that tokens of perceived action can exhibit more or less representational overlap with tokens of planned action (MacKay 1987; Prinz 1990, 1997; Hommel *et al.* 2001).

A major implication of the assumptions formulated in the ideomotor approach refers to situations in which people watch other people's actions and/or their outcomes. In such a situation, the perception of another's actions should address those representational structures that are also involved in one's own planning and control of those actions. This, in turn, leads to the prediction summarized in the principle of *action modulation through perception* that the perception of another's actions and/or their outcomes should modulate the planning and control of an ongoing action in the observer. This modulation can be expected to depend on the degree of similarity between the actions perceived and those concurrently planned.

3. EXPERIMENTAL EVIDENCE
In the following, we will summarize empirical evidence demonstrating that actions can be modulated through concurrent (or previous) perception of other's actions. On the methodological side, the discussion will show that action modulation through perception can be found across a variety of different experimental paradigms, suggesting that the phenomenon is a rather general one, and that its scope goes far beyond imitation itself. On the theoretical side, we will focus on the question of what aspects of an observed action are important in modulating concurrent behaviour, especially when increasingly complex actions are considered.

(a) Observation of simple, intransitive movements

Brass *et al.* (2001) used a movement initiation paradigm in which participants had to execute a predefined finger movement (either an upward or downward movement of the finger) as soon as an imperative movement of a finger displayed on a computer screen occurred. Importantly, the type of finger movement to be executed was not dependent on the movement observed (which was also either an upward or downward finger movement), rather it was predefined and constant within a block. Hence, in some trials the movement observed was the same movement that had to be executed, and in other trials it was a different one. The question was whether the type of finger movement observed would influence the concurrent execution of the participant's finger movement. The results indicated pronounced compatibility effects in a series of experiments conducted: prespecified upward movements were initiated much faster when an upward, as compared with a downward, finger movement was the go signal, and the opposite was the case for downward movements. This pattern of results suggests that even for such simple responses as initiating a predefined movement, the perception of a concurrent movement by someone else can have substantial impact. Similar studies (e.g. Brass *et al.* 2000; Stürmer *et al.* 2000) reported compatibility effects for other types of tasks and responses (e.g. effector selection, movement type selection). Bach & Tipper (2007) showed that concurrent action observation can even influence personal-trait judgements and affect finger-key or foot-key responses in a person identification task.

Two recent studies (Berthental *et al.* 2006; Press *et al.* 2008) tried to distinguish whether these correspondence effects with simple intransitive movements are because of the left–right and/or up–down spatial properties of the observed actions that might activate response codes corresponding to these spatial properties, or instead, to the type of gesture displayed and/or executed. Both studies were able to confirm that correspondence effects can also be found under conditions where spatial compatibility is eliminated. Especially revealing in this context, is a study by Belopolsky *et al.* (2008), who showed that automatic motor activation can also occur for the anatomically matching hand (i.e. the spatially incongruent hand when people are facing each other), when participants watch a model's movements.

A related topic that has been addressed in more recent studies concerns the question of whether interfering effects of movement observation are specific to the observation of biological as opposed to non-biological movements. In a recent study by Kilner *et al.* (2007), participants observed either human movements or ball movements, both with either a biological (i.e. bell-shaped) velocity profile or a non-biological (i.e. constant) velocity profile. Results indicated that the form of the observed stimulus movement (i.e. ball versus human) is irrelevant for the effect, since the observation of both incongruent ball movements and incongruent human movements produced interference with a simultaneously executed action. Furthermore, the velocity profile of the observed movement was of critical importance only for human movements: when the observed human movement had a non-biological velocity profile, no interference occurred for incongruent movements, whereas for incongruent ball movements both stimuli with a biological and non-biological velocity profile produced interference. These results demonstrate that interfering effects of movement observation are not restricted to the observation of human or biological movements, but can occur for a broader range of stimuli. This is consistent with the ideomotor approach and its assumption that not only the observation of bodily movements, but also the observation of their environmental effects can activate corresponding behaviour. In line with this assumption, a study by Stanley *et al.* (2007) demonstrated that the observation of moving dot stimuli with either biological or non-biological velocity profiles produced interference only when participants believed that the dot movements were produced by a human actor.

To summarize, research on the observation of simple movements of humans or objects suggests that movement activation through movement observation is not a mechanism specialized for human or biological movements. Instead, it seems to be a rather general phenomenon that occurs as a byproduct of the general organization of our sensorimotor system. However, in the studies reported so far, the crucial assumption of ideomotor theory, namely that perception of movements as well as the perception of end states or effects of those movements may prime corresponding actions, has not been directly tested, because only simple, intransitive movements were studied. To test this assumption, one would have to study the effects of action observation for goal-directed actions that have both a bodily movement component and an associated action goal or action effect. Here, questions arise as to whether both components of the goal-directed action (i.e. the bodily movement and its effect) may become activated through action perception, what their relative importance is, and under what conditions one or the other component will come into play. In the subsequent sections, studies addressing one or more of these questions will be discussed.

(b) Observation of goal-directed actions

In the studies discussed so far, participants were required to perform a movement in response to a stimulus. This is different in action induction paradigms in which *spontaneous* movements of an individual as a reaction to the observation of movement events in the environment are studied. Such movements have often been called ideomotor movements (cf. Prinz 1987). A classical example is the spontaneous occurrence of body movements in a person watching another's movements. Two kinds of mechanisms for movement induction have been proposed—perceptual and intentional induction. Perceptual induction is thought to rely on similarity between what is being perceived and what is induced. An observer will tend to repeat in his or her actions what he or she sees

happening in the scene. Intentional induction, on the other hand, is thought to rely on intended rather than perceived events. Hence, an observer tends to perform actions that he or she believes are instrumental in reaching the goal of an observed action. A task that allows one to study these two kinds of movement induction has been used by Knuf *et al.* (2001). In this task, participants watched a ball moving towards a target on a screen, either hitting or missing it. During the initial instrumental phase, the participant could manipulate either the ball (ball condition) or the target's horizontal position (target condition) with corresponding joystick movements. In the subsequent induction phase, the participant could no longer influence the ball or the target's position. The hypothesis was, however, that small joystick movements would nonetheless occur, reflecting either perceptual or intentional ideomotor movements of the participant. If perceptual ideomotor movements occurred, these should always follow the ball's travel. Intentional ideomotor movements should only occur in trials with upcoming misses, not in trials with upcoming hits. This is because instrumental activity to prevent the miss was only indicated when the ball was going to miss the target. For instance, when the participant was in the ball condition and the ball was going to miss the target on the left side, these ideomotor movements should occur to the right. However, in the target condition, leftward misses should induce ideomotor movements to the left (in order to bring the target to the left).

The results obtained in a number of experiments within this paradigm (see Knuf *et al.* 2001) can be summarized as follows. First, the direction of ball movement did not have much impact on ideomotor movements. Second, ideomotor activity was almost absent in trials with upcoming hits. Third, in trials with upcoming misses, pronounced ideomotor movements whose direction depended on the object under initial control (ball versus target) and the side of the upcoming miss were observed in the predicted direction. This pattern of results strongly suggests that ideomotor movements (at least in the paradigm described) are much more influenced by intentional rather than perceptual induction. However, further experiments indicated that perceptual induction may also occur, for instance, in effectors that are not involved in instrumental control of the action (like the head or the feet). Movements of these effectors tended to follow the direction of the ball, but were much weaker overall than intentional ideomotor movements. In summary, experiments on action induction suggest that different features of an observed action may activate corresponding movements, with action goals being particularly effective in inducing ideomotor action.

Wohlschläger & Bekkering (2002*a*) used an intentional imitation paradigm to investigate whether there are differences in the imitation of target-directed movements and of movements not oriented towards a target. Participants had to execute downward finger movements on a table surface in response to finger movements displayed as stimuli on a screen. The stimulus pictures to be imitated differed with respect to the hand that executed the finger movement, and

with respect to the spatial position to which the movement was directed (either contralateral or ipsilateral to the hand). In the target condition finger movements shown were directed towards red target dots drawn on the table, whereas in the non-target condition these red dots were absent. Although the presence or absence of a target dot had no general impact on the results, there was a specific effect on ipsilateral movements: imitation of ipsilateral finger movements was much faster when they were directed towards a target. Furthermore, when a contralateral movement was required, participants more often used the wrong (ipsilateral) finger when the red target dot was present as compared with when not present. These results suggest that movement goals are of special importance for imitation. However, a study by Franz *et al.* (2007), who contrasted the mirror imitation condition (i.e. imitating a model as though looking in a mirror) used by Wohlschläger & Bekkering (2002*a*) with a non-mirror imitation condition (i.e. imitating a model using the anatomically matching effector), showed that much more emphasis is placed on selecting the correct effector than on selecting the correct goal in non-mirror imitation.

There are other studies showing an advantage of goals over movements in intentional imitation. Developmental studies have often used hand-and-ear tests (e.g. Bekkering *et al.* 2000; Gleissner *et al.* 2000; Gattis *et al.* 2002). In these tests, a child is asked to imitate an adult who performs one of the following four gestures: reaching for his or her left ear with the right or left arm or reaching for his or her right ear with the right or left arm. Ipsilateral movements are quite easy to imitate, but 3–5-year-old children make frequent errors in trials where the reaching arm has to cross the body midline to the contralateral side. In these cases, the wrong arm is chosen much more frequently (effector error) than the wrong ear (goal error): children copy the goal but choose the simpler, ipsilateral movement to reach it. This pattern is only exhibited when the gestures are really goal directed. When the same gestures are demonstrated without actually reaching for the ear, both types of errors are equally frequent (Gleissner *et al.* 2000).

A recent study by Bird *et al.* (2007) used a similar task to investigate imitation errors in adults. In the pen-and-cups task they used, participants observed a (video) model move a centrally located pen into one of the two coloured cups using his or her right or left hand. In addition, the way the pen was grasped was varied (it could either be grasped with the thumb pointing up or pointing down). Participants had to imitate the action displayed in an anatomically compatible but egocentrically incompatible way (i.e. if the model used the left hand, the participant also had to use his or her left hand). Bird *et al.* (2007) found the typical pattern of results also obtained in previous studies with live models. Participants made fewer object errors (i.e. chose the wrong cup) than effector errors (i.e. chose the wrong hand) and fewer effector errors than grip errors (Wohlschläger & Bekkering 2002*b*; Avikainen *et al.* 2003). This pattern of results has often been taken as evidence for a hierarchical decomposition of the perceived act in imitation

(cf. Gattis *et al.* 2002). Perceived goals or ends (e.g. objects and their treatments) are more important and hierarchically higher than perceived means like effectors or movement characteristics. Because of capacity limitations, it may be that imitators only encode the most important aspects of the observed action (e.g. the perceived goal), which in turn leads to errors in exactly copying other aspects of the action (e.g. the effector used).

However, in subsequent experiments, Bird *et al.* (2007) showed that the error pattern in the pen-and-cups task is probably caused by task-general processes (e.g. attentional selection, stimulus-response translation or response selection) rather than owing to an imitation-specific hierarchy of goals. In one of the experiments they conducted, they demonstrated that the lower number of cup errors in the pen-and-cups-task is owing to the fact that the cups are usually coloured and thus more easily discriminated than the two hands. In a condition where the model was wearing coloured gloves and the cups were not coloured, the error pattern reversed, and more cup- than hand-errors occurred. Furthermore, this error pattern also occurred when participants were asked to describe, rather than imitate the actions seen, indicating that the processes involved are task general rather than imitation specific.

To sum up, research on the observation and imitation of goal-directed actions suggests that different components of an action (i.e. the effector or the action goal) may become activated in action observation, depending on which features of the action attract the observer's attention in the respective action context. This has been shown with intentional imitation tasks and also with paradigms in which more incidental influences of action observation were investigated, suggesting that the mechanisms that govern the control of imitative and non-imitative actions are rather similar.

(c) *Observation of tool-use actions*
Typically, imitative behaviour in humans does not occur for simple pointing or grasping movements that can easily be learned and performed without observing someone else. Rather, intentional imitation occurs for complex actions and skills that would take much time and effort to learn by ourselves or by verbal instruction. A good example is tool use. We learn how to eat with a knife and fork by observing our parents, and we learn to drive a car by observing the driving instructor. Hence, in particular, the learning of new tool-use skills (as opposed to other kinds of motor behaviour that are not culturally transmitted) requires excellent imitative capabilities of an individual. Furthermore, it has been suggested that the establishment of a culture of tool-use behaviour in humans might, in turn, have influenced their ability for imitation. According to Iriki (2006), the learning and execution of refined tool-use actions contributes to the emergence of a sense of the subjective self because it raises the question of whether tools (and in a similar way, also the parts of one's own body) have to be regarded as belonging to oneself, or to the

outer world. In this sense, tool users learn to see their body parts and also themselves from a third-person perspective, and develop the ability to imitate the form of an observed action independent of its current goal or environmental triggers. Hence, there seem to be close bidirectional links between imitation, on the one hand, and tool use, on the other.

To study the effects of action observation in tool use, we used a tool-use task (cf. Massen & Prinz 2007*a*,*b*) in which participants had to operate a horizontal lever that was mounted on a plastic plate and movable around one of two possible pivotal points (figure 1).

The task was to touch one of two target points (situated at different distances in front of the person) with the lever by moving its handle in the appropriate direction (towards or away from the body), taking into account the momentarily active pivotal point of the lever. For example, if the lever was movable around the left pivotal point, as shown in figure 1, the handle on the right side of the lever had to be moved away from the body (i.e. arm extension was required) to touch the far target point and towards the body (i.e. arm flexion) to touch the near target point. If the lever was movable around the right pivotal point, its handle had to be moved towards the body to touch the far target point, and away from the body to touch the near target point. Each pivotal point thus implemented a specific mapping between the direction of the bodily movement and the direction of the target reached (i.e. the target-to-movement mapping or action rule). For the left pivotal point this mapping is compatible (i.e. the direction of the bodily movement and the direction of the target reached are always in the same direction), whereas for the right pivotal point this mapping is incompatible (bodily movement direction and target direction are always opposite to each other). In each trial, participants were informed about the target and about the valid pivotal point of the lever by way of light diodes that were lit at the respective target and pivot locations.

In a series of experiments we conducted (Massen & Prinz 2007*b*), two participants took turns acting, observing the lever action of the other person in trial $n-1$ and subsequently executing a lever action themselves in trial n. Each participant used his or her own lever device. To dissociate priming effects owing to observing the target, the bodily movement or the target-to-movement-mapping of a lever action, trial transitions from $n-1$ to n were manipulated in four conditions. In the first condition, only the bodily movement direction (towards or away from the body) was repeated from trial $n-1$ (observation) to trial n (execution), whereas target and target-to-movement mapping (i.e. pivotal point) changed. In the second condition, only the target point was repeated. In the third condition, only the target-to-movement mapping was repeated; in the fourth condition, all the three components were repeated.

With this set-up, it is possible to analyse the effect of observing the other's action in trial $n-1$ on executing an action in trial n. If only the target-to-movement mapping of the observed action is extracted, task
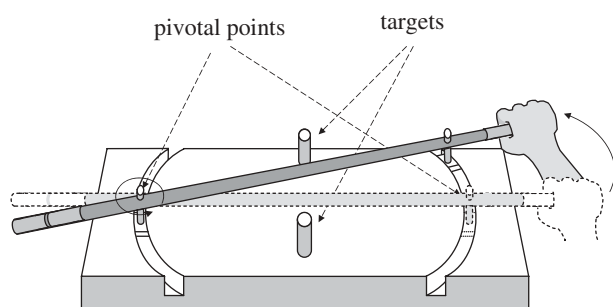
Figure 1. Lever device used in the experiments on the observation of tool-use actions. If the left pivotal point is active (as depicted in the figure), the handle of the lever has to be moved away from the body to touch the far target point and towards the body to touch the near target point. If the right pivotal point is active, the handle of the lever has to be moved towards the body to touch the far target point and away from the body to touch the near target point.

performance (e.g. in terms of reaction times or error rates) should be best in the condition where this mapping is repeated from trial $n-1$ to n. If the observed action is mainly coded with respect to its goal, irrespective of the means through which it is achieved, performance should be best in the condition where only the target of the action is repeated. As a third possibility, movement-based resonance might dominate performance. In this case, participants should perform best in the condition where only the bodily movement direction is repeated. As a fourth prediction, one might also expect performance to be best in the condition where all components of the action are repeated, because such a resonance mechanism might be helpful for true imitation (i.e. for exactly copying the behaviour of others).

In one of the experiments we conducted, two people sat side by side, taking turns to operate their lever devices. Both used the right arm to operate the handle on the right side of their lever device. A participant who was already familiar with the task served as the model person and sat on the left side. Only the data of the participant who was sitting on the right were analysed. To motivate new participants to pay attention to the model's actions, they were instructed to take turns in acting with an expert and to pay attention to this expert's actions. The model person was instructed to also watch the actions of the new participant in turn. The question was whether performance in a given trial n would differ as a function of what had been observed in the previous trial. Results indicated significantly shorter reaction times in those conditions in which participants had observed an action with the same target-to-movement mapping in the previous trial when compared with the conditions in which a different target-to-movement mapping had been observed. Importantly, this was even true when the target of the observed action and the direction in which the bodily movement was executed were completely different, indicating a considerable degree of abstraction of the observed behaviour. These results provide direct behavioural evidence for a simulation of others' tool-use behaviour during observation in a natural situation. Only if the model's and/or the

tool's behaviour is mentally simulated, would one expect an advantage in the condition where the target-to-movement-mapping remains the same but a different movement with a different target has to be executed. Participants seem to construct an internal model of the person's and/or tool's behaviour that goes beyond the concrete movement-to-target situation and activates complementary actions for a changed target situation.

In a further experiment, we tested whether the effects obtained were owing to the fact that participants observed the bodily movements (and associated lever movements) executed by the model person, or whether they were rather owing to participants' observation of the task information given to the model by way of the light diodes on the target and pivotal points. Put differently, it might have been the case that not the observation of movements *per se* but, rather, an internal simulation or imagination of the model's task on the basis of these cues that might have caused the effects. We tested this possibility by running a condition in which the light diodes at the target and pivot locations of the model's lever device were covered in such a way that they could not be seen from the viewpoint of the participant. The results were very similar to those previously obtained. Participants showed better performance when they had observed an action with the same target-to-movement mapping as in the previous trial, irrespective of whether target and bodily movement direction were also the same.

What do these results reveal about mechanisms of action priming through action observation? In our view, the fact that we do not find any priming effects for target and/or movement repetition does not imply that there is no activation of target and/or movement representations in observing others' actions in general. However, for the more complex actions investigated in this study, the target-to-movement mapping seems to be the most salient or important aspect of the action, and other aspects of the action are neglected. This view fits with the conclusions already drawn in the study by Bird *et al*. (2007): participants do not always attend to the goal of an action, rather they attend to the most salient aspect of an observed action. In many cases, and especially in tool use, this might be the general and abstract way (*the how*) an action is performed (in terms of the action rule or target-to-movement mapping that is applied to achieve a certain goal). There is also evidence for the extraction of rules from observational sequence learning (e.g. Heyes & Foster 2002; Badets *et al*. 2006). However, the rules acquired in these paradigms are more abstract ones related to the sequential order and/or timing of components in a sequence of actions, and cannot be considered as rules coding the target–movement relationship of a specific goal-directed action.

A potential criticism that might arise with respect to our interpretation that the target-to-movement mapping is the most salient or important aspect of a tool-use action concerns the fact that in the experiments reported so far, the tool's behaviour was a rather salient aspect of the experimental situation because it frequently changed its behaviour (i.e. the target-to-movement mapping) between trials. In contrast to

this behaviour, simpler everyday tools usually have a constant target-to-movement mapping. Thus, the effects reported might be driven mainly by the interesting and unusual behaviour of the tool, rather than being a general feature of the observation of tool-use actions. In addition, participants observed the same tool-use actions they also had to execute when it was their turn. Thus, not only were the observed tool-use actions interesting because they frequently changed, they were also highly task-relevant in the sense that participants themselves switched between different target-to-movement mappings.

To address this potentially moderating factor, we ran another experiment. In this experiment, the target-to-movement mapping was constant for a given individual and, instead, varied between participants. The observer either executed tool-use actions with a compatible target-to-movement mapping or with an incompatible target-to-movement mapping. Furthermore, the model also executed actions with either a compatible or incompatible target-to-movement mapping. Consequently, in one group the observed model executed actions with the same target-to-movement mapping as the participant, whereas in the other group the participant observed actions with a different target-to-movement mapping than he himself executed during the course of the experiment. For the group in which mappings were identical between observer and model, target and movement direction could either both remain constant from trial $n-1$ to trial n, or both change. In the group with different mappings between observer and model, either only the target direction or only the movement direction was the same between observation in trial $n-1$ and execution in trial n.

The question was whether the target-to-movement mapping would still become activated under these conditions or whether other aspects of the observed action (i.e. its target or the movement) might become more salient. If there is still an activation of the target-to-movement mapping, then the performance of participants who watch tool-use actions with a different target-to-movement mapping should be worse than that of participants watching actions with the same target-to-movement mapping. Furthermore, in this case, it seems unlikely that the activation of the action rule is only because of an unusual behaviour of the tool because the tool's behaviour is constant across trials and therefore less salient in the situation. The procedure of the experiment was the same as in the other experiments with one exception: in each trial, only the target of the action was indicated by a light diode, whereas the target-to-movement mapping was explained to the participant before the experiment and the respective pivotal point did not change in the course of the experimental session.

Error rates for both the groups are shown in figure 2. A one-way analysis of variance (ANOVA) with group (same mapping-observers versus different mapping-observers) as between-subjects factor revealed a significant main effect of group ($F_{1, 22} = 4.6$; MSE = 9.6; $p < 0.05$). Participants who watched actions with a different target-to-movement mapping committed significantly more errors than participants who watched actions with the same target-to-movement mapping.
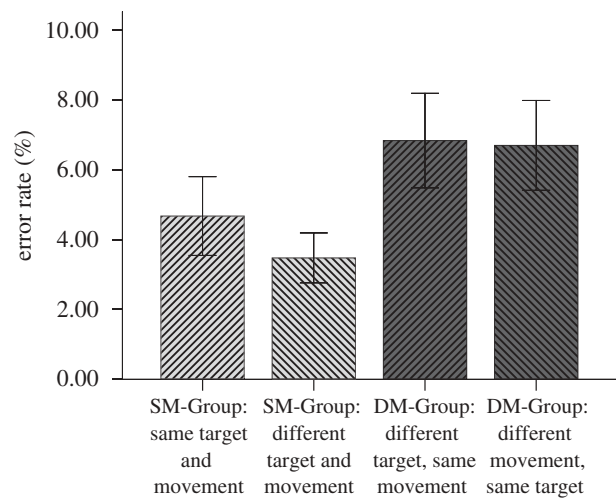

Figure 2. Error rates (%) as a function of group (same-mapping observers versus different-mapping observers) and condition (same target and movement observed; different target and movement observed; different target and same movement observed; different movement and same target observed). Error bars represent standard errors. SM, same mapping; DM, different mapping.

Within-subjects analyses in the same-mapping group indicated no differences between the conditions in which participants had observed an action with the same target and movement in trial $n-1$ or an action with a different target and movement ($F_{1, 11} = 1.2$; MSE = 7.4). Furthermore, the different-mappings group showed no difference between the only target-repeated condition and the only movement-repeated condition ($F_{1, 11} < 1$; MSE = 17.7).

Reaction times are depicted in figure 3. A one-way ANOVA with group as between-subjects factor revealed no significant main effect of group ($F_{1, 22} < 1$; MSE = 912.9). Within-subject analyses in the same mapping-group indicated significantly longer reaction times when participants had observed an action with the same target and movement in trial $n-1$ as compared with when they had observed an action with a different target and movement ($F_{1, 11} = 15.9$; MSE = 31.9; $p < 0.01$). In the different-mappings group, it did not matter whether participants had observed an action with the same target or an action with the same movement in trial $n-1$ ($F_{1, 11} < 1$; MSE = 136.2).

To summarize, the results show that participants who observe tool-use actions with a different target-to-movement mapping than they themselves execute make significantly more errors than participants who observe actions with the same target-to-movement mapping. Furthermore, if mappings are different, it does not matter whether an action with the same target or an action with the same movement is observed. However, if actions with the same mapping are observed, participants are faster to initiate their own action when they have observed an action with the other target and movement in the previous observation trial than when an action with the same target and movement was observed.

These results replicate and extend those of the previous experiments. Even when the action rule of an observed action does not change across trials and
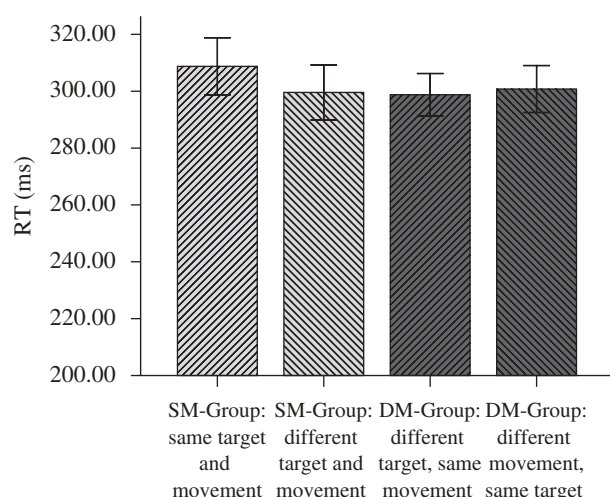
Figure 3. Reaction times (RT; ms) as a function of group (same-mapping observers versus different-mapping observers) and condition (same target and movement observed; different target and movement observed; different target and same movement observed; different movement and same target observed). Error bars represent standard errors. SM, same mapping; DM, different mapping.

might therefore be considered a subordinate aspect of the action observed, it seems to be activated in a similar way as in the case where it frequently changes between trials. In our view, this pattern of results renders alternative explanations for our effects in terms of increased attention to the tool's complex behaviour unlikely. However, it should be noted that the results obtained leave open the question as to whether participants simulate the behaviour of the physical device observed (ignoring the movements of the person observed), or whether they simulate the movements of the person observed (cf. the imitation versus emulation debate in Whiten *et al.* (2009) and Tennie *et al.* (2009)) in this. Note that the action rule can be defined both with respect to the person (e.g. in order to reach target, move arm in opposite direction versus in order to reach target, move arm in same direction) and with respect to the lever (e.g. right pivotal point is active versus left pivotal point is active). This question has to be answered in further studies. However, from the viewpoint of the ideomotor approach this issue is not crucial, as both the observation of a person's movements and the observation of the effects of those movements (e.g. in terms of movements of a physical device) should activate a corresponding action in the observer.

A somewhat unexpected feature of the results is the finding that reaction times in the same-mapping group were actually faster when participants had observed an action with the other target and movement in trial $n-1$ as compared with when both target and movement remained constant from trial $n-1$ to trial n. This result was not expected, but might be related to recent evidence demonstrating that depending on the action context, action observation is more probable to result in activation of complementary rather than identical actions (Newman-Norlund *et al.* 2007). According to Newman-Norlund *et al.* (2007), activation of complementary actions occurs especially in

joint-action contexts, for instance, when one person hands an object to another person. Although participants in our experimental situation do not directly act together to achieve a common goal, the turn-taking character of the situation might nonetheless facilitate the execution of a complementary rather than an identical action. The fact that this effect occurred only in the same-mapping group supports this interpretation because complementary actions usually occur when two people are engaged in the same task. An alternative explanation might be derived from studies on task-switching demonstrating that if one feature of a task changes from trial $n-1$ to trial n, it is sometimes easier for participants if other task feature(s) also change, especially if the latter belong to hierarchically subordinate task dimensions (e.g. Kleinsorge & Heuer 1999). In our case, one task feature could be the person that is to execute the action. If this task feature changes, it might be easier for participants if other, subordinate features of the action (i.e. the target and the movement) also change. Further research is needed to clarify this issue.

4. IMPLICATIONS FOR THE IDEOMOTOR APPROACH TO HUMAN IMITATION

In the beginning of this article, we started with the ideomotor approach and its implications for explaining imitative behaviour in humans. One of the key assumptions was that the perception of another person's action or its remote effects can trigger the same action in the observer because perceptual event representations and representations of actions share a common representational domain. On the one hand, the empirical evidence reviewed in this article strongly supports this view. It has been shown that the perception of both bodily movements and their remote goals or effects can influence ongoing motor activity, as it is predicted by the principle of action modulation through perception. Furthermore, the evidence supports the view that rather similar mechanisms seem to be responsible for influences of action observation on action production in imitative and non-imitative behaviours. One example is the fact that situational or contextual constraints seem to determine which of the components of an observed action has the power to influence ongoing action both in intentional imitation and incidental action observation. Although some studies support the view of a major role for goals in both intentional imitation and non-imitational action observation, other studies have shown that observed bodily movement characteristics can also have a strong influence if they are salient in the respective action context.

However, while many of the findings can easily be accounted for, the evidence on action observation in more complex actions like tool-use actions, in particular, seems to warrant some extension of the ideomotor approach. First of all, the finding that in the observation of these complex skills, a more abstract feature like the mapping between bodily movements and external goals can become activated needs some discussion. As has already been said, the ideomotor view entails the assumption that humans have to

learn a bidirectional association between actions and their associated effects. Without this learning, the perception of action effects cannot trigger the corresponding action in the observer. This simple statement does not take into account, however, that one and the same action effect may be associated with many different actions depending on the action context. For instance, there are a number of ways to get from one point to another, including walking, riding a bike, using a train or plane or paying someone to carry you. Likewise, one and the same bodily movement may become associated with many different action outcomes depending on the action context. For instance, pressing a button directly in front of you may turn on the light in your living room, ring the bell in your neighbour's flat, cause the elevator to go to the second floor or set off an alarm in the hospital. All these examples show that learning associations between actions and action effects are context specific and that movements that are elicited by the perception of an action effect will also depend on the context in which the effect is observed. An empirical demonstration for this context specificity of acquired response–effect associations has been provided by Kiesel & Hoffmann (2004). In their study, left (or right) keypress responses were followed by fast movements of a target in one context and by slow movements in the other, with each response leading to fast or slow effects equally often. Reaction times for the same response decreased in contexts with fast effects and increased in contexts with slow effects, providing evidence for the notion that the same actions were accessed by different effect anticipations depending on the task context. While the examples mentioned above refer more to environmental or situational contexts, the term context can, in general, be applied to any instance that defines a specific mapping of bodily movements into environmental effects, including machines and tools. Often, the relationship between movements and effects in such contexts can be described with a general action rule or abstract function that applies to many specific movement–effect instances. A related notion from research on motor skill learning is that of a motor schema (cf. Schmidt 1975) or action schema, which is supposed to contain relatively abstract invariants and variable, situationally defined parameter values. If one acknowledges that many goal-directed actions are specific instances of a general relationship between bodily movements and environmental effects, it becomes clear that describing an action only in terms of the concrete bodily movement and its associated effects eliminates a major, though not directly visible, aspect of the action. The findings we obtained suggest that, for many complex actions, the motor schema linking movements and effects is the most important or salient component of the action because it represents its invariants. To account for these findings, the ideomotor approach would have to be extended by broadening its description and conception of actions. Actions would have to be described in terms of their motor patterns, their environmental effects and in terms of the abstract invariants of which they are instances. Such an extension would allow for the prediction that the perception of another's action or its effects not only has the power to activate a concrete response but also the entire action schema to which the observed movement–effect episode belongs.

To summarize, in the present review, we have presented and discussed empirical evidence for the principle of action modulation through action perception. While much of the evidence can easily be accounted for by the ideomotor approach, some extension seems necessary when it comes to explaining effects of action observation in complex actions, for instance, when tools are involved. Furthermore, the evidence reviewed strongly suggests that similar mechanisms are responsible for influences of action observation on action production in imitative and non-imitative behaviours. With respect to the cognitive mechanisms mediating imitation, these findings imply that imitation is not based upon special purpose mechanisms, but, rather, relies on the general organization of learning and action control in humans.

REFERENCES

Avikainen, S., Wohlschläger, A., Liuhanen, S., Hanninen, R. & Hari, R. 2003 Impaired mirror-image imitation in Asperger and high-functioning autistic subjects. *Curr. Biol.* **13**, 339–341. (doi:10.1016/S0960-9822(03)00087-3)

Bach, P. & Tipper, S. P. 2007 Implicit action encoding influences personal-trait judgments. *Cognition* **102**, 151–178. (doi:10.1016/j.cognition.2005.11.003)

Badets, A., Blandin, Y. & Shea, C. H. 2006 Intention in motor learning through observation. *Q. J. Exp. Psychol.* **59**, 377–386. (doi:10.1080/02724980443000773)

Belopolsky, A. V., Olivers, C. N. L. & Theeuwes, J. 2008 To point a finger: attentional and motor consequences of observing pointing movements. *Acta Psychol.* **128**, 56–62. (doi:10.1016/j.actpsy.2007.09.012)

Bekkering, H., Wohlschläger, A. & Gattis, M. 2000 Imitation of gestures in children is goal-directed. *Q. J. Exp. Psychol.* **53**, 153–164. (doi:10.1080/027249800390718)

Berthental, B. I., Longo, M. R. & Kosobud, A. 2006 Imitative response tendencies following observation of intransitive actions. *J. Exp. Psychol. Hum. Percept. Perform.* **32**, 210–225. (doi:10.1037/0096-1523.32.2.210)

Bird, G., Brindley, R., Leighton, J. & Heyes, C. 2007 General processes, rather than 'goals', explain imitation errors. *J. Exp. Psychol. Hum. Percept. Perform.* **33**, 1158–1169. (doi:10.1037/0096-1523.33.5.1158)

Brass, M. & Heyes, C. 2005 Imitation: is cognitive neuroscience solving the correspondence problem? *Trends Cogn. Sci.* **9**, 489–495. (doi:10.1016/j.tics.2005.08.007)

Brass, M., Bekkering, H., Wohlschläger, A. & Prinz, W. 2000 Compatibility between observed and executed finger movements: comparing symbolic, spatial and imitative cues. *Brain Cogn.* **44**, 124–143. (doi:10.1006/brcg.2000.1225)

Brass, M., Bekkering, H. & Prinz, W. 2001 Movement observation affects movement execution in a simple response task. *Acta Psychol.* **106**, 3–22. (doi:10.1016/S0001-6918(00)00024-X)

Elsner, B. & Hommel, B. 2001 Effect anticipation and action control. *J. Exp. Psychol. Hum. Percept. Perform.* **27**, 229–240. (doi:10.1037/0096-1523.27.1.229)

Elsner, B. & Hommel, B. 2004 Contiguity and contingency in action-effect learning. *Psychol. Res.* **68**, 138–154. (doi:10.1007/s00426-003-0151-8)

Franz, E. A., Ford, S. & Werner, S. 2007 Brain and cognitive processes of imitation in bimanual situations: making inferences about mirror neuron systems. *Brain Res.* **1145**, 138–149. (doi:10.1016/j.brainres.2007.01.136)

Gattis, M., Bekkering, H. & Wohlschläger, A. 2002 Goal-directed imitation. In *The imitative mind: development, evolution and brain bases* (eds A. N. Meltzoff & W. Prinz), pp. 183–205. Cambridge, UK: Cambridge University Press.

Gleissner, B., Meltzoff, A. N. & Bekkering, H. 2000 Children's coding of human action: cognitive factors influencing imitation in 3-year-olds. *Dev. Sci.* **3**, 405–414. (doi:10.1111/1467-7687.00135)

Greenwald, A. G. 1970 Sensory feedback mechanisms in performance control: with special reference to the ideomotor mechanism. *Psychol. Rev.* **77**, 73–99. (doi:10.1037/h0028689)

Greenwald, A. G. 1972 On doing two things at once: time sharing as a function of ideomotor compatibility. *J. Exp. Psychol.* **94**, 52–57. (doi:10.1037/h0032762)

Heyes, C. M. & Foster, C. L. 2002 Motor learning by observation: evidence from a serial reaction time task. *Q. J. Exp. Psychol. A* **55**, 593–607. (doi:10.1080/02724980143000389)

Heyes, C. M. & Ray, E. 2000 What is the significance of imitation in animals? *Adv. Study Behav.* **29**, 215–245. (doi:10.1016/S0065-3454(08)60106-0)

Hommel, B., Müsseler, J., Aschersleben, G. & Prinz, W. 2001 The Theory of Event Coding (TEC): a framework for perception and action planning. *Behav. Brain Sci.* **24**, 849–937.

Iriki, A. 2006 The neural origins and implications of imitation, mirror neurons and tool use. *Curr. Opin. Neurobiol.* **16**, 660–667. (doi:10.1016/j.conb.2006.10.008)

James, W. 1890 *The principles of psychology* (2 vols). New York, NY: Holt.

Kiesel, A. & Hoffmann, J. 2004 Variable action effects: response control by context-specific effect anticipations. *Psychol. Res.* **68**, 155–162. (doi:10.1007/s00426-003-0152-7)

Kilner, J. M., Hamilton, A. F. & Blakemore, S. J. 2007 Interference effect of observed human movement on action is due to velocity profile of biological motion. *Soc. Neurosci.* **2**, 158–166. (doi:10.1080/17470910701428190)

Kleinsorge, T. & Heuer, H. 1999 Hierarchical switching in a multi-dimensional task space. *Psychol. Res.* **62**, 300–312. (doi:10.1007/s004260050060)

Knuf, L., Aschersleben, G. & Prinz, W. 2001 An analysis of ideomotor action. *J. Exp. Psychol. Gen.* **130**, 779–798. (doi:10.1037/0096-3445.130.4.779)

Kunde, W. 2001 Response-effect compatibility in manual choice reaction tasks. *J. Exp. Psychol. Hum. Percept. Perform.* **27**, 387–394. (doi:10.1037/0096-1523.27.2.387)

Lotze, H. 1852 In *Medicinische Psychologie oder Physiologie der Seele*. Leipzig, Germany: Weidmannsche Buchhandlung.

MacKay, D. G. 1987 *The organization of perception and action*. New York, NY: Springer-Verlag.

Massen, C. & Prinz, W. 2007a Programming tool-use actions. *J. Exp. Psychol. Hum. Percept. Perform.* **33**, 692–704. (doi:10.1037/0096-1523.33.3.692)

Massen, C. & Prinz, W. 2007b Activation of action rules in action observation. *J. Exp. Psychol. Learn. Mem. Cogn.* **33**, 1118–1130. (doi:10.1037/0278-7393.33.6.1118)

Newman-Norlund, R. D., van Schie, H. T., van Zuijlen, A. M. J. & Bekkering, H. 2007 The mirror neuron system is more active during complementary compared with imitative action. *Nat. Neurosci.* **10**, 817–818. (doi:10.1038/nn1911)

Press, C., Bird, G., Walsh, E. & Heyes, C. 2008 Automatic imitation of intransitive actions. *Brain Cogn.* **67**, 44–50. (doi:10.1016/j.bandc.2007.11.001)

Prinz, W. 1987 Ideomotor action. In *Perspectives on perception and action* (eds H. Heuer & A. F. Sanders), pp. 47–76. Hillsdale, NJ: Erlbaum.

Prinz, W. 1990 A common-coding approach to perception and action. In *Relationships between perception and action: current approaches* (eds O. Neumann & W. Prinz), pp. 167–203. Berlin, US: Springer-Verlag.

Prinz, W. 1997 Perception and action planning. *Eur. J. Cogn. Psychol.* **9**, 129–154. (doi:10.1080/713752551)

Schmidt, R. A. 1975 A schema theory of discrete motor skill learning. *Psychol. Rev.* **82**, 225–260. (doi:10.1037/h0076770)

Stanley, J., Gowen, E. & Miall, R. C. 2007 Effects of agency on movement interference during observation of a moving dot stimulus. *J. Exp. Psychol. Hum. Percept. Perform.* **33**, 915–926. (doi:10.1037/0096-1523.33.4.915)

Stürmer, B., Aschersleben, G. & Prinz, W. 2000 Correspondence effects with manual gestures and postures: a study on imitation. *J. Exp. Psychol. Hum. Percept. Perform.* **26**, 1746–1759. (doi:10.1037/0096-1523.26.6.1746)

Tennie, C., Call, J. & Tomasello, M. 2009 Ratcheting up the ratchet: on the evolution of cumulative culture. *Phil. Trans. R. Soc. B* **364**, 2405–2415. (doi:10.1098/rstb.2009.0052)

Whiten, A., McGuigan, N., Marshall-Pescini, S. & Hopper, L. M. 2009 Emulation, imitation, over-imitation and the scope of culture for child and chimpanzee. *Phil. Trans. R. Soc. B* **364**, 2417–2428. (doi:10.1098/rstb.2009.0069)

Wohlschläger, A. & Bekkering, H. 2002a Is human imitation based on a mirror-neuron system? Some behavioural evidence. *Exp. Brain Res.* **143**, 335–341. (doi:10.1007/s00221-001-0993-5)

Wohlschläger, A. & Bekkering, H. 2002b The role of objects in imitation. In *Mirror neurons and the evolution of mind and language* (eds M. Stamenor & V. Gallese), pp. 101–114. Amsterdam, The Netherlands: John Benjamins.