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THEORETICAL NOTE

Effect-Based Action Control With Body-Related Effects: Implications for Empirical Approaches to Ideomotor Action Control

Roland Pfister
Julius Maximilians University of Würzburg

Ideomotor accounts of human action control posit that human agents represent actions in terms of their perceivable consequences; selecting, planning, and initiating a voluntary action is thus assumed to be mediated by action-effect anticipations. Corresponding empirical investigations have often employed arbitrary effects in the agent's environment to study action-effect learning and effect-based action control. This strategy has provided accumulating evidence in support of ideomotor mechanisms, but the widespread focus on environment-related action effects has also created misperceptions of what ideomotor accounts aim to explain. Moreover, this strategy has also given rise to misunderstandings of critical epistemological limitations, especially regarding the theoretical relevance of negative results in common experimental paradigms. These recent developments call for a theoretical clarification of the concept of action effects. I propose that many misunderstandings can be resolved by embracing the theoretical role of body-related compared to environment-related actions' effects. I show how the concept of such effects may inform current debates and how this focus can guide future research related to ideomotor action control, with a main challenge being the derivation of testable and falsifiable theories from the ideomotor framework.

Keywords: action control, ideomotor theory, action effect anticipation, body-related effects, falsification

Bodily movements are a core product of the human cognitive machinery. They are the only way of influencing the environment that is available in the humans biological repertoire, be it by grasping an object of interest, by walking toward a desired location, or by using articulatory muscles to utter a statement. Such movements also do not occur randomly, but rather they are often employed in a goal-directed manner; that is, subjective states such as goals and intentions are somehow translated into coordinated patterns of muscular activity.

A classical framework for understanding the translation of intentions into bodily movements has been proposed in the form of ideomotor theory (for recent reviews, see Hommel, 2013; Shin, Proctor, & Capaldi, 2010).[1] The philosophical roots of ideomotor approaches to action control originate in the 19th century, and they converge on the notion that humans and other animals acquire bidirectional links between their own motor activity and resulting sensory consequences (Harleß, 1861; Herbart, 1825; Lotze, 1852; cf. Stock & Stock, 2004). Bidirectionality implies that motor activity not only allows for predicting possible consequences of a movement but also allows for anticipation of desired consequences to reactivate the corresponding motor patterns.

Correspondence concerning this article should be addressed to Roland Pfister, Department of Psychology III, Julius Maximilians University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany. E-mail: roland.pfister@psychologie.uni-wuerzburg.de

The seemingly simple assumptions of ideomotor theory present a plausible and elegant framework for understanding how the capacity for voluntary actions is acquired during ontogeny and how individual actions are cognitively represented (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). Furthermore, ideomotor theory stresses that anticipated consequences (i.e., action goals) not only are used for deciding between different possible actions but are the actual psychological mechanism behind planning and initiating an action (Kunde, Koch, & Hoffmann, 2004; Pfister & Kunde, 2013; Shin & Proctor, 2012).

Despite its popularity in philosophical accounts of voluntary action during the 19th century, ideomotor theory was harshly criticized by mainstream psychologists of the behaviorist era (Thorndike, 1913; see also Miller, Galanter, & Pribram, 1960). Thus, it was not until the second half of the 20th century and onward that the cognitive mechanisms proposed by ideomotor theory started to receive continued attention from empirical studies (Greenwald, 1970c; Hoffmann, 1993; Hommel, 1996), and I briefly sketch these studies in the following section.

[1] I use the term *theory* because ideomotor approaches have often been discussed under this label (e.g., Greenwald, 1970a; Shin, Proctor, & Capaldi, 2010). To foreshadow a main argument of this article, most ideomotor approaches should not be seen as testable scientific theories, however, but rather as theoretical frameworks that do not yield clear predictions for typical experimental situations.

Empirical Approaches to Ideomotor Action Control

Several empirical approaches have been proposed to uncover ideomotor mechanisms, including action-effect acquisition paradigms and action-effect compatibility paradigms.[2]

Action-effect acquisition paradigms target the process of action-effect learning, and these studies typically employ two distinct phases: an acquisition phase and a test phase (Elsner & Hommel, 2001; Hommel, 1996). In the acquisition phase, participants perform different actions such as pressing a left or right key, and each of these actions produces an arbitrary effect, such as a high or low tone. Repeated co-occurrence of action and effect should, according to ideomotor theory, establish bidirectional associations between each action and its contingent effect. These associations are probed for in the following test phase, during which the previous effect stimuli (e.g., tones) are presented as imperative stimuli. In this test phase, the previous effects were found to facilitate the associated response in several studies, suggesting that ideomotor learning had indeed taken place during acquisition (see also Dignath, Pfister, Eder, Kiesel, & Kunde, 2014; Elsner & Hommel, 2004; Hoffmann, Lenhard, Sebald, & Pfister, 2009; Hommel, Alonso, & Fuentes, 2003; Meck, 1985; Wolfensteller & Ruge, 2011).

Action-effect compatibility paradigms, by contrast, target the anticipation of upcoming action effects, and these studies manipulate the relation of features of to-be performed actions to features of the resulting effects (Kunde, 2001). Participants thus perform actions that vary on a particular dimension (e.g., left vs. right), and these actions trigger effects with either compatible features on this dimension (e.g., a left action triggering a left effect) or incompatible features (e.g., a left action triggering a right effect). Even though the effects appear only after action execution, the experimental design ensures that participants can predict and thus anticipate the upcoming effect for each of their actions (Pfister, Kiesel, & Melcher, 2010). According to the common logic of dimensional overlap, stimulus features prime actions with compatible features (*element-level compatibility*; Kornblum, Hasbroucq, & Osman, 1990; Proctor & Reeve, 1990). Following ideomotor theory, such priming should also occur for features of anticipated effects, and this is precisely what studies have reported (see also Ansorge, 2002; Badets, Pesenti, & Olivier, 2010; Chen & Proctor, 2013; Földes, Philipp, Badets, & Koch, 2017; Kunde, 2003; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014; Yamaguchi & Proctor, 2011; Zwosta, Ruge, & Wolfensteller, 2013).

The empirical approaches just reviewed—action-effect acquisition paradigms and action-effect compatibility paradigms—have been successful in providing evidence in support of the basic claims of ideomotor theory. At the same time, however, these approaches bear the danger of creating a biased view of what ideomotor theory aims to explain. A main source of confusion has been the operationalization of action effects in almost all previous studies that had employed either design. The gist of the argument that follows is to provide a detailed analysis of this operationalization and to highlight how this operationalization has created confusion regarding what empirical studies on ideomotor action control can, and what they cannot, show.

What Is an Action Effect?

By definition, an action effect is a change of sensory input that is triggered by a bodily movement. Action-effect acquisition paradigms and action-effect compatibility paradigms build on this definition by coupling arbitrary sensory events in the environment, such as sounds or changes of visual input, to certain actions. This procedure is elegant because it allows for minute experimental control over the effects, and it therefore enables a structured study of ideomotor action control. However, the procedure of coupling movements with arbitrary visual or auditory effects may also be misleading at times, because it seems to suggest that the effects under experimental control are the only action effects that are involved in the task at hand.[3]

Viewing the action effects under experimental control as an exhaustive description of which effects are produced in the described paradigms is not warranted, though. Even simple actions such as key presses lead to a variety of effects, including proprioceptive changes due to the finger movement, corresponding visual changes relating to the moving finger, and possible reafferences from the key's surface (Prinz, 1998). All these action effects can potentially be used to represent and control a particular action in addition to, or instead of, the additional effects that are triggered in the context of the experiment. In fact, early philosophical formulations of ideomotor theory focused almost exclusively on immediate kinesthetic effects of bodily movements (Harleß, 1861; Herbart, 1825; Lotze, 1852). These accounts adopted a developmental perspective in assuming that "great variety of incidental movements results in the unborn and the newborn" (Harleß, 1861, p. 66; cited after Pfister & Janczyk, 2012), which allows for associating motor activity with resulting proprioceptive changes of the moving body. These experiences were assumed to be the cornerstone of acquiring initial bidirectional associations between motor activity and resulting bodily sensations.[4] Accordingly, anticipations relate to the "visual, tactile, kinaesthetic, [sensations] originally produced by the performance of the movement itself" (Washburn, 1908, p. 280).

Even though later formulations of ideomotor theory highlighted action effects to be equifunctional in that each action may, in principle, become represented in terms of any effect that it contingently produces, these formulations still explicitly acknowledged the possibility of representing an action solely in terms of its effects on the moving body (for a related discussion, see Sutter, Sülzenbrück, Rieger, & Müsseler, 2013).

The possibility of representing an action via different types of effects begs the question of whether there are qualitative differ-

[2] Previous reports have typically adopted the more technical terminology *response* instead of *action* when describing action-effect acquisition paradigms and action-effect compatibility paradigms. I use the term *action* in the following discussion to stress that the participants' responses in these paradigms were instrumental in that they produced additional effects in the environment. This feature is less obvious in other procedures, such as modality compatibility paradigms (Greenwald, 1970a, 1970b) and studies on action-induced blindness (Müsseler & Hommel, 1997a, 1997b), that were inspired by ideomotor theory.

[3] This notion is reinforced by terminology such as *response-effect compatibility* or *action-effect compatibility,* which suggests that effects are confined to what occurs after an action has been carried out (see Pfister & Kunde, 2013, for a related argument).

[4] Similar ideas were later introduced under the terms of *body babbling* in the developmental literature (Meltzoff & Moore, 1997; Verschoor, Spapé, Biro, & Hommel, 2013) and *motor babbling* in the literature on computational motor control and cognitive robotics (e.g., Demiris & Dearden, 2005).

ences between different types of action effects. A first explicit distinction between different types of effects was put forward by James (1890), who distinguished between *resident* and *remote* effects (see also Janczyk, Skirde, Weigelt, & Kunde, 2009; Jordan, 2013). Resident effects refer to proprioceptive or kinesthetic changes produced by the moving limbs, whereas remote effects describe any other effect that may be perceived with the remaining senses (and even effects that are merely construed, in case of what James termed *very remote* effects). The distinction of resident and remote effects thus pertains to different sensory channels that register the effects.

A second distinction of different types of action effects relates to how closely and consistently certain effects are coupled with a specific movement. Corresponding distinctions have been labeled *direct* versus *indirect* (Taub, Bacon, & Berman, 1965) or *intrinsic* versus *extrinsic* (Greenwald, 1970c). Direct, intrinsic effects are related to resident effects in James's (1890) terminology in that they refer to effects that necessarily accompany an action at all times, but they differ from resident effects in that they are not restricted to a specific sensory modality such as proprioception. The visual image of the moving limb would thus count as a direct, intrinsic effect, and at the same time it would count as a remote effect. Because direct, intrinsic effects of a movement will almost exclusively pertain to the body of the moving agent whereas indirect, extrinsic effects will almost exclusively pertain to effects on the environment, we have recently used the latter distinction under the terms *body-related effects* and *environment-related effects* (Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Pfister & Kunde, 2013; Wirth, Pfister, Brandes, & Kunde, 2016), and I adopt this terminology in this article.[5]

Even though classical and contemporary formulations of ideomotor theory differ regarding the emphasis that they put on either body-related or environment-related effects, they both hold that an action can be represented in terms of either type of effect. As a consequence, body-related effects are explicitly seen as sufficient to represent an action in all available formulations of ideomotor theory. This critical feature is sometimes overlooked, as becomes evident from critical statements such as "Essentially, it [ideomotor theory] holds that the key mental representation of actions happens in terms of the effects of action *in the outside world* [emphasis added]" (Chambon & Haggard, 2013, p. 359). It also becomes evident from statements that the process of action selection "has largely been ignored in discussions of IM [ideomotor theory]" (Chambon & Haggard, 2013, p. 360). Keeping body-related action effects in the picture is necessary, though, to assess the informative value of most, if not all, empirical studies on ideomotor action control, as argued in the following section.

Empirical Approaches Revisited

Even though most empirical approaches and, accordingly, recent theorizing have focused on environment-related effects, ideomotor theory always incorporates the possibility of controlling an action via anticipations of body-related actions effects. This state of affairs implies that providing arbitrary visual or auditory effects to participants cannot represent a strong experimental test of ideomotor theory, because it does not allow for falsifying the theory.

Consider, for example, an influential study on action-effect learning that closely follows the experimental protocol of action-effect acquisition paradigms sketched previously (Elsner & Hommel, 2001, Experiment 1). In the study, participants initially worked through an acquisition phase of 200 trials in which they freely decided between pressing a left key with their left index finger or a right key with their right index finger. Their responses contingently produced either a high or a low effect tone. In the test phase, participants had to respond to the previous effect stimuli, and they were assigned to one of two groups, a nonreversal group and a reversal group. Participants in the nonreversal group responded with the key that had triggered the tone stimulus in the acquisition phase, whereas participants in the reversal group had to respond with the opposite key. As described earlier, the participants in the nonreversal group were faster than were the participants in the reversal group. This pattern of results supports ideomotor accounts by suggesting that participants came to represent their actions of the acquisition phase in terms of the contingently following effect tones.

Now, suppose for a moment that the study had returned different results by showing no difference between the nonreversal group and the reversal group, and also suppose that the study had had sufficient power to argue that this pattern of results indicates substantial evidence for the absence of an effect (compared to absence of evidence). Would these results be difficult to reconcile with ideomotor theory? They would not. The results would, in fact, be just as in line with ideomotor theory as are the results that were actually reported. Following ideomotor theory, a negative pattern of results would simply indicate that participants had represented their actions in terms of body-related effects such as the feeling of moving the left or right index finger, the corresponding visual image, or tactile reafferences when pressing down the key. It is important to note that ideomotor theory does not allow for predicting which types of effects are used to represent an action in the first place, because it states only that any one of the available effects will be used. The instructions given to the participants even seem to suggest a representation in terms of body-related rather than environment-related effects (Elsner & Hommel, 2001, p. 233): "[Participants] were verbally instructed to choose freely which key to press but were instructed to use the keys in a random order and about equally often. . . . Participants were not informed about the R-E [response-effect] mapping but were told that the [effect] tones were completely irrelevant for the task and should therefore be ignored." These instructions clearly seem to favor a representation of the response in terms of either the spatial location of the key or the corresponding motor patterns (cf. Hommel, 1993), though ideomotor theory does not yield any specific predictions for the experimental setup at hand.

Negative findings in studies using the action-effect acquisition paradigm therefore cannot be taken as evidence against ideomotor theory, and the same applies to studies using the action-effect

[5] The terms *proximal* and *distal* have also sometimes been used to refer to body-related and environment-related effects, respectively (e.g., Jordan, 2013; Ladwig, Sutter, & Müsseler, 2012), though they come with a markedly different meaning in the context of the related theory of event coding (Hommel et al., 2001). Furthermore, these terms can also be easily confused with *proximal intentions* and *distal intentions* (Pacherie, 2008), which are discussed in later sections of this article.

compatibility paradigm. This limitation even applies to studies that explicitly aimed to manipulate body-related action effects by coupling predictable (vibro)tactile effects to the participants' responses (Janczyk et al., 2009; Pfister, Janczyk, Gressmann, et al., 2014; Thébault, Michalland, Derozier, Chabrier, & Brouillet, 2018; Wirth et al., 2016). These latter studies still used additional effects, which, according to ideomotor theory, may or may not be used to represent the corresponding actions. Negative findings in action-effect acquisition paradigms and action-effect compatibility paradigms thus cannot be taken to suggest that ideomotor theory holds for only certain settings but not others, as has been suggested by some authors (Herwig, Prinz, & Waszak, 2007; see also Cox & Hasselman, 2013). In a more general sense, this reasoning implies that negative results of studies in typical experimental paradigms do not allow for evaluating the truth status of ideomotor theory.[6]

If both positive and negative findings are in line with ideomotor theory, what can one learn from these studies after all? Positive results, as provided by most studies in the published literature, are obviously informative because they are difficult to reconcile with other psychological approaches to action control, such as motor programs (Keele, 1968). These findings thus support the notion that anticipated action effects govern the selection, planning, and initiation of voluntary actions (Kunde, 2006; Kunde et al., 2004). Negative results, by contrast, do not contradict ideomotor theory, but they do constrain what kinds of effects are preferentially recruited for action control in which situation. To exemplify this informative value, I now turn to a specific debate related to action control for free-choice versus forced-choice actions.

Free-Choice Versus Forced-Choice Actions

Humans either act to attain a self-chosen goal or try to respond accurately in a given situation. These two requirements form two poles of a continuum with varying emphasis on internal goal states and situational demands. The two poles may technically be described as free-choice and forced-choice actions, and they have also been discussed under such labels as *self-initiated* versus *externally triggered* (Jahanshahi et al., 1995; Obhi & Haggard, 2004; Wiese et al., 2004), *endogenous* versus *exogenous* actions (Khalighinejad, Di Costa, & Haggard, 2016; Pfister, Heinemann, Kiesel, Thomaschke, & Janczyk, 2012), or *intention-based* versus *stimulus-based* actions (Herwig et al., 2007; Keller et al., 2006). These studies showed a range of neurophysiological and behavioral differences between both types of actions.

Regarding ideomotor action control, Herwig et al. (2007) replicated the action-effect learning experiment of Elsner and Hommel (2001) but varied the design of the acquisition phase for different groups of participants. One group performed an acquisition phase with freely chosen actions as in the original study, and another group performed an acquisition phase with forced-choice actions that were signaled by a stimulus that prompted either a left or a right response in each trial. Evidence for action-effect learning was present for only freely chosen actions but not for forced-choice actions, and this pattern of results was replicated in a number of studies (see Herwig & Horstmann, 2011; Herwig & Waszak, 2009, 2012). These results led Herwig et al. (2007) to suggest that ideomotor action control "is subject to a far-reaching constraint: It holds for endogenously driven actions only!" (p. 1540).

Initial attempts to assess the validity of this suggestion focused on showing that action-effect learning as captured in action-effect acquisition paradigms does indeed take place for forced-choice actions (Gaschler & Nattkemper, 2012; Hommel, Lippelt, Gurbuz, & Pfister, 2017; Pfister, Kiesel, & Hoffmann, 2011; Wolfensteller & Ruge, 2011; Zwosta et al., 2013). Even though this interpretation seems to have gained some consensus in the field (see, e.g., Hommel, 2013), the discussion related to free-choice and forced-choice actions may create the impression of searching for boundary conditions of ideomotor action control with action-effect acquisition paradigms or action-effect compatibility paradigms. This question might be ill-posed for the mentioned study designs because of the possibility of representing an action via body-related effects. By contrast, a more viable and productive response to findings such as the systematic absence of learning effects in the settings of Herwig et al. (2007) may be to embrace the informative value of these results in showing when participants rely on body-related action effects to control their actions and when they rely on environment-related effects.

Interpreting negative results from studies on action-effect learning and action-effect anticipation in this manner may also help to specify theoretical accounts that propose *intentional weighting* of different feature codes depending on the agent's current intentions (Hommel, 2009; Hommel et al., 2001; Memelink & Hommel, 2013). Initial attempts to describe when actions are predominantly represented in terms of either body-related effects or environment-related effects can be traced back at least to James's (1890) formulation of ideomotor theory. More precisely, he proposed that resident effects may primarily govern action control during early stages of learning (i.e., mostly during early ontogeny and while acquiring a new skill), whereas remote effects may dominate in later stages (James, 1890, pp. 518–519):

> There can be no doubt whatever that the mental cue may be either an image of the resident or of the remote kind. Although, at the outset of our learning a movement, it would seem that the resident feelings must come strongly before consciousness . . . later this need not be the case. The rule, in fact, would seem to be that they tend to lapse more and more from consciousness, and that the more practiced we become in a movement, the more "remote" do the ideas become which form its mental cue.

In line with this proposal, studies on tool use have suggested a shift from body- or motor-related representations to more remote, tool-based representations given that certain constraints are met (Maravita & Iriki, 2004; Sülzenbrück & Heuer, 2013). Accordingly, visual attention is readily deployed to the end point of a tool in addition to, or even instead of, the location of the operating hand (Collins, Schicke, & Röder, 2008; Reed, Betz, Garza, & Roberts, 2010; Sülzenbrück, 2012; Sülzenbrück & Heuer, 2013). Furthermore, two recent studies set out to investigate the impact of *response selection efficiency* on typical paradigms used to address ideomotor theory (Gozli, Huffman, & Pratt, 2016; Wolfensteller & Ruge, 2014). Gozli et al. (2016), for instance, showed that an impact of action effects comes into play mainly when participants

[6] Negative results would of course also be compatible with views that divide action control into mechanisms that are *ideomotor* and others that are *non-ideomotor* in nature (Herwig, Prinz, & Waszak, 2007), but they do not allow for deciding between both alternatives.

have some difficulty in selecting the appropriate response, for example, due to the presence of stimuli with response-incompatible spatial features or due to low levels of stimulus intensity (converging arguments follow from distribution analyses of response times in the action-effect compatibility paradigm; e.g., Kunde, 2001; Wirth et al., 2016; but see Sidarus & Haggard, 2016). From an ideomotor perspective, response selection in many experimental tasks comes down to retrieving those body-related effects that fulfill the current goal of pressing a particular key (in order to respond correctly), because participants will tend to adhere to the instructed goal of responding in one way or another (Gozli, 2017; Prinz, 1998). If this process is inefficient, however, or if environment-related action effects happen to be sufficiently salient (Janczyk, Yamaguchi, Proctor, & Pfister, 2015), then participants will likely represent their actions in terms of these additional effects.[7]

Is Ideomotor Theory a Scientific Theory?

The arguments of the preceding sections show that typical empirical approaches to ideomotor theory may accumulate evidence in support of the theory but that, at the same time, typical experimental designs do not allow for rejecting the theory, because negative findings can also be easily explained in terms of ideomotor mechanisms. Furthermore, not only does this criticism apply to the experimental paradigms reviewed but it is indeed difficult to imagine any hypothetical experimental situation that would allow for a strict, critical test of ideomotor theory. In other words, ideomotor theory cannot be easily falsified by empirical data (see also Herbort & Butz, 2012; Oriet, Stevanovski, & Jolicoeur, 2001; Sanders, 2001).

Falsifiability, in turn, has often been highlighted as a cornerstone of scientific theories (Popper, 1935). Following Popper's (1935) falsificationism, ideomotor theory would thus not count as a strictly scientific theory, because it does not allow for predicting certain phenomena to occur.[8] From an epistemological position, it thus seems useful to view ideomotor theory not as a testable theory but rather as a theoretical *framework* that is consistent with numerous empirical observations.

If ideomotor approaches are theoretical frameworks without clear predictions for empirical investigations, what exactly is their contribution to the study of human action control? A first contribution is that theoretical frameworks allow for stimulating exploratory investigations that would not have been conducted against the background of alternative frameworks. Such studies have certainly been emerged in the last two decades (e.g., Camus, Hommel, Brunel, & Brouillet, 2018; Elsner & Hommel, 2001; Huffman, Gozli, Hommel, & Pratt, 2018; Kunde, 2001; Müller, 2016; Pfister, Dignath, Hommel, & Kunde, 2013). As a second contribution, however, theoretical frameworks also allow for deriving testable (i.e., falsifiable) theories for more specific situations. This second possibility has only recently gained traction in ideomotor-inspired research. Fully implementing this possibility represents a major challenge for future psychological work on action control, as I describe in the following section.

Future Challenges

Accepting the epistemological limitations of general ideomotor accounts allows for a new, structured approach to studies on human action control from an ideomotor-inspired perspective. This approach combines the general mechanisms proposed by ideomotor accounts with the available evidence from empirical studies to formulate a derivative theory that predicts which types of action effects should become represented for specific types of situations. Critically, this approach does not (and cannot) aim at dividing action control in ideomotor and non-ideomotor aspects (Herwig et al., 2007); rather, it provides a testable version of a specific derivative theory that can be supported or contradicted by empirical findings.

A successful example for such a derivative theory is the planning and control model of motorvisual priming (Thomaschke, 2012; Thomaschke, Hopkins, & Miall, 2012). Motorvisual priming describes the established phenomenon that planning and executing an action affects perceptual processes; however, the previous literature has shown that motorvisual priming may at times impair perception of stimuli that are congruent with the anticipated action effects (Müsseler & Hommel, 1997a, 1997b), whereas it has been shown to facilitate perception of effect-congruent stimuli in other studies (Fagioli, Hommel, & Schubotz, 2007; Wykowska, Schubö, & Hommel, 2009). The planning and control model makes the testable assumption that these seemingly diverging findings—all of which can be accounted for by general ideomotor approaches—depend on whether an action has already been initiated or whether it is merely planned at the time of stimulus encounter. The model further holds that action planning and action control involve qualitatively different representations (categorical vs. metric formats). This allows for precise predictions of when motorvisual priming should facilitate or impair perception, and empirical studies can test (and possibly falsify) such hypotheses (Thomaschke, Miall, Rueß, Mehta, & Hopkins, 2018).

A second challenge for future research is the connection of ideomotor approaches to action control with theories on intentions and intentionality (Mylopoulos & Pacherie, 2017). Such theories highlight that movements can be controlled by different intentions, and these intentions are often construed in a hierarchical fashion (Brand, 1984; Mele, 1992; Pacherie, 2008). The distal-proximal-motor model (Mylopoulos & Pacherie, 2018), for instance, assumes a cascade of overarching, abstract intentions (distal intentions), which interface with more situated intentions related to short-term goals (proximal intentions), which finally give rise to movement-related intentions (movement intentions). It seems tempting to equate ideomotor mechanisms with movement intentions when considering body-related effects and with proximal intentions when considering environment-

[7] It is a rarely discussed possibility that body-related and environment-related effects may serve different functions for deciding what to do on the one hand and for actually initiating this behavior on the other hand. It seems plausible to assume that environment-related effects mostly guide decision-making whereas body-related effects might be preferentially recruited for action initiation (based on the "two-hyphen" view discussed by Prinz, 1987; see also Hoffmann et al., 2009).

[8] Following Kerlinger's (1973) definition, a scientific theory is a set of "constructs (concepts), definitions, and propositions . . . with the purpose of explaining and predicting . . . phenomena" (p. 9). By contrast, theoretical physicists have recently suggested that falsifiability should no longer be seen as a defining feature for scientific theories as long as the theory in question provides an elegant and consistent explanation for existing findings (e.g., Carroll, 2014). Irrespective of whether one agrees with this proposal, it is certainly desirable to be able to specify and predict which situations promote action representation in either body-related or environment-related terms.

related effects. This putative similarity again highlights that actions can aim at a variety of different goals and that even at the level of environment-related effects, it is often possible to distinguish between various types of effects that differ in terms of abstractness and in terms of temporal contiguity with the causing action. It is important to note, however, that the distal-proximal-motor model also assumes a dynamical interplay within and between these different layers. Studying such an interplay requires settings with continuous rather than discrete actions and corresponding effects (e.g., Hommel et al., 2017; Wirth, Pfister, Janczyk, & Kunde, 2015) and study designs that explicitly take theories on intentions into account (e.g., Becchio, Sartori, Bulgheroni, & Castiello, 2008; Georgiou, Becchio, Glover, & Castiello, 2007; Pfister, Janczyk, Wirth, et al., 2014). The interface of intentions and actions also calls for considering movements that are initiated without conscious intentions, as in the case of overlearned, habitual behavior (de Wit & Dickinson, 2009; de Wit et al., 2012; Dickinson, 1985; Tricomi, Balleine, & O'Doherty, 2009).

Conclusions

Theoretical accounts of ideomotor action control hold that actions are represented, planned, and initiated in terms of the effects that they consistently produce. Even though empirical approaches have typically employed arbitrary environment-related effects, body-related effects such as proprioceptive information relating to the moving body part are, in principle, sufficient for ideomotor action control.

The theoretical possibility of ideomotor action control via body-related action effects yields clear limits in that the proposed ideomotor mechanisms cannot be easily falsified by empirical studies; from an epistemological point of view, such accounts should thus be seen as theoretical frameworks rather than testable scientific theories. Despite this epistemological limitation, the ideomotor framework still appears to be a viable account in that it has stimulated numerous empirical investigations, and it is likely to continue to serve this function in the years to come. A major challenge for such future work is to establish testable (i.e., falsifiable) derivative theories that predict when actions are represented mainly in environment-related terms and when they are represented in body-related terms. Embracing a possible role of body-related action effects may further contribute to resolving current debates by clarifying several misunderstandings that have emerged in the literature in recent years. These misunderstandings also help to draw attention to the fact that studying the representation, planning, and initiation of voluntary actions is a surprisingly challenging endeavor at the very frontier of psychological inquiry.

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