IDEOMOTOR ACTION CONTROL: ON THE PERCEPTUAL GROUNDING OF VOLUNTARY ACTIONS AND AGENTS

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“In the beginning was the act”, Faust concluded in Goethe’s (1808/1963) same-named play, and this is pretty much the take-home message of the present chapter. Most theoretical accounts of the selection, planning, and control of human action follow the seemingly self-evident custom to begin their theoretical analysis with the stimulus, which is then taken to trigger, and to some degree “explain”, action-related processes and the eventual execution of the action. Indeed, almost all textbooks of cognitive psychology and the cognitive neurosciences try to make us believe that humans are basically passive couch potatoes who are waiting for some external events that make us get up and move. In view of the experimental paradigms that cognitive scientists employ to investigate action-related processes and mechanisms this seems to make perfect sense: The standard cognitive experiment uses stimulus presentation as the major means to control the experimental situation and people’s responses to those stimuli are considered the dependent rather than the independent variable under study. And yet, the impression we get from our everyday life seems to suggest the exact opposite. Most stimuli we are exposed to are actually generated by our own actions: we smell the cologne because we have put it into our face, taste the marmalade because we dipped our croissant into it, laugh about the comedian’s joke because we have switched on the TV, and so forth and so on. Hence, we do not passively await stimuli to get us going but actively generate and seek the stimuli we intend to perceive. In the beginning is the act.

As argued by Hommel, Müsseler, Aschersleben, and Prinz (2001a, 2001b), the only historical tradition that has wholeheartedly embraced this theoretical perspective is the line of ideomotor theorizing. Ideomotor theory integrates several lines of reasoning and has a long tradition (Stock & Stock, 2004; Prinz, 1987), which found its first systematic expression in the works of Lotze (1852) and James (1890). Given its emphasis on internal representations, it is not surprising that the approach fell into disgrace during the (from a cognitive perspective) dark ages of purist behaviorism, as exemplified by Thorndike’s (1913) comparison of ideomotor theory with the animistic beliefs of underdeveloped tribes. But the approach did not fare much better in the most influential post-behaviorist manifesto of a cognitive psychology of action—Miller, Galanter, and Pribram’s (1960) “Plans and the structure of behavior”, where the authors reduced the intellectual contribution of ideomotor thinking to the (sometimes used) hyphen between “ideo” and “motor”. However, the ideomotor approach regained some credibility through the work of Greenwald (1970) and others, and now benefits from the positive press of theoretically related frameworks and concepts, like embodied cognition and mirror neurons. In the present chapter, I would like to briefly summarize the main assumptions of the Theory of Event Coding (Hommel et al., 2001a), the arguably most comprehensive ideomotor approach to date (for recent reviews, see Hommel, 2009; Shin, Proctor & Capaldi, 2010), and then turn to what I consider the most pressing theoretical questions to be addressed in order to validate this approach. In particular, I will discuss whether agents do acquire action-effect associations the way the theory suggests; whether agents really anticipate the perceptual effects of their actions, as the theory holds; whether these anticipations really control the action, rather than being a mere byproduct; what aspects of an action these anticipations actually control; and, finally, what implications the theory and the processes it assumes have for the representation of the agent’s self.

Ideomotor action control

The major aim of ideomotor theorizing is to explain how the cognitive representation of an intended action—an “idea” that is—can move one’s body in such a way that this action is actually carried out—i.e., result in motor activity. The original concept of the “ideo” part was strongly connected to conscious representations (e.g., James, 1890), which given the mainly introspective methods used by the early theorists is not surprising. More modern approaches like those of Greenwald (1970) and Hommel et al. (2001a) tend to be agnostic with respect to the question whether action goals do or do not require conscious representation to be effective, even though some authors still feel that conscious representation is essential (e.g., Baars, 1988; for a review, see Hommel, 2007).

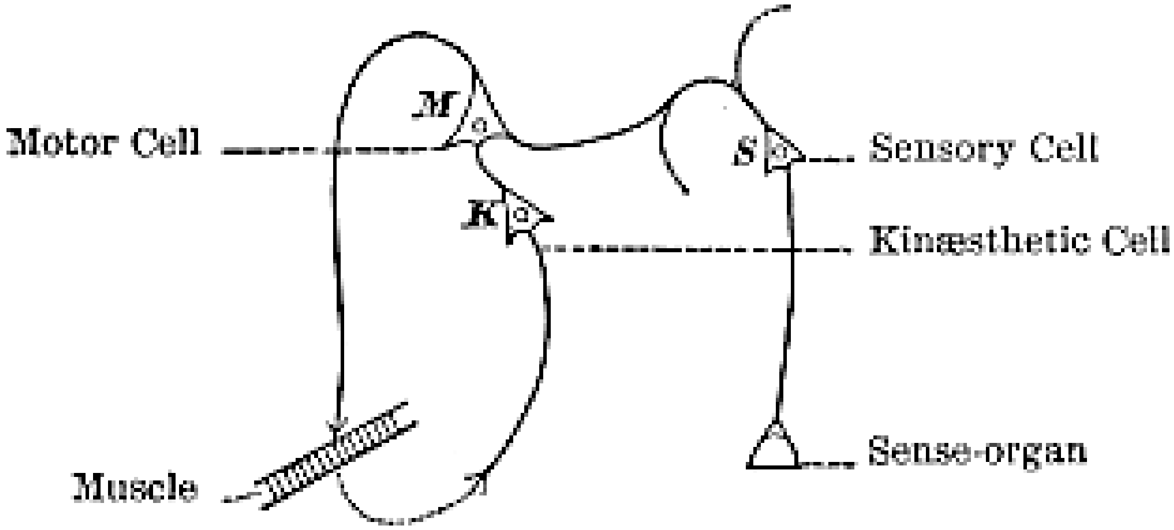


Figure 1: James' (1890) neural model of acquiring ideomotor control (see text for explanation). Taken from James (1890, p. 582).

The main mechanism underlying ideomotor action control has been nicely sketched in James' (1890) neural-network model (see Figure 1). Here, the hypothetical motor neuron *M* is assumed to move a particular *Muscle* that, when being activated, produces kinesthetic feedback coded by neuron *K*. The more often this loop is active, be it through pre- or post-natal reflexes or random motor noise, or active exploration of one's own body and the world, the more often M and K will be concurrently active. Under the assumption that co-activation leads to association—which anticipates Hebb's dictum that "what fires together wires together" (cf., Greenwald, 1970)—this implies that M and K will become associated. Ideomotor theory holds that the association relating the two will be bidirectional, so that M can now be intentionally activated by endogenously activating K—that is, by "thinking of" the feedback that one may want to produce intentionally. The same scenario can be developed for any other sensory (visual, auditory, etc.) action feedback, so that M becomes coded in a multisensory fashion. If so, actively anticipating any sensory action effect will spread activation to, and thus gain control over M, which renders the resulting action truly voluntary.

How do agents acquire action-effect associations?

According to ideomotor theory, voluntary action emerges through experience and the knowledge about the relationship between particular muscle movements and particular sensory effects that this experience allows one to acquire. Before having acquired this knowledge, the agent cannot have any idea about what outcome a given action might have. If we define intentional or voluntary action as a set of movements carried out to reach a particular goal (which presupposes knowledge about expected action effects), this implies that it is action-effect knowledge that turns aimless movements into voluntary action. This line of reasoning necessarily implies that the acquisition of knowledge about action and their effects is involuntary and spontaneous—if volition is the result of action-effect learning it cannot be its cause or precondition. In view of influential claims that question the existence of involuntary learning (e.g., Brewer, 1974; Shanks, 2010), it is thus important to ask whether the learning theory underlying ideomotor reasoning is tenable at all. Hence, we need to ask whether action-effect acquisition is truly spontaneous.

Another challenge for ideomotor reasoning is its implicit assumption that motor patterns and codes of sensory action effects are associated in a bidirectional fashion. Clearly, this assumption is necessary for the theory to work. In the scenario sketched in Figure 1, the motor code M would usually be activated sometime before K, simply because K can only fire when M has passed some threshold to activate the Muscle, which then needs to move before K is triggered. In the acquisition phase, the activation of M therefore always precedes the activation of K, which mirrors the external sequence of the movement and its sensory consequences. This scenario does not change if we assume that sensory action-effect codes may also be visual, auditory, and so on, as effects necessarily follow their cause. Intentionally producing the action, however, requires the use of the emerging association in the reverse direction: the codes of the sensory effects need to be activated in order to activate M and, eventually, the Muscle. Intentional action thus requires the spread of activation from sensory codes to motor codes, which again requires the association between them to work either way. One may consider this an odd assumption, as it implies that the information about the original sequence (first M then K) is deleted from memory, at least at the representational level where action-effect associations are stored. Moreover, claiming that bidirectional associations exist seems to amount to assuming the efficacy of backward conditioning (i.e., acquiring a conditioned response to a conditioned novel stimulus that follows, rather than precedes, the unconditioned stimulus), which does not seem to fit with numerous failures to demonstrate this phenomenon (for a review, see Mackintosh, 1974) and theoretical claims that it cannot exist in principle (Pavlov, 1927). Accordingly, we need to ask whether action-effect associations are truly bidirectional.

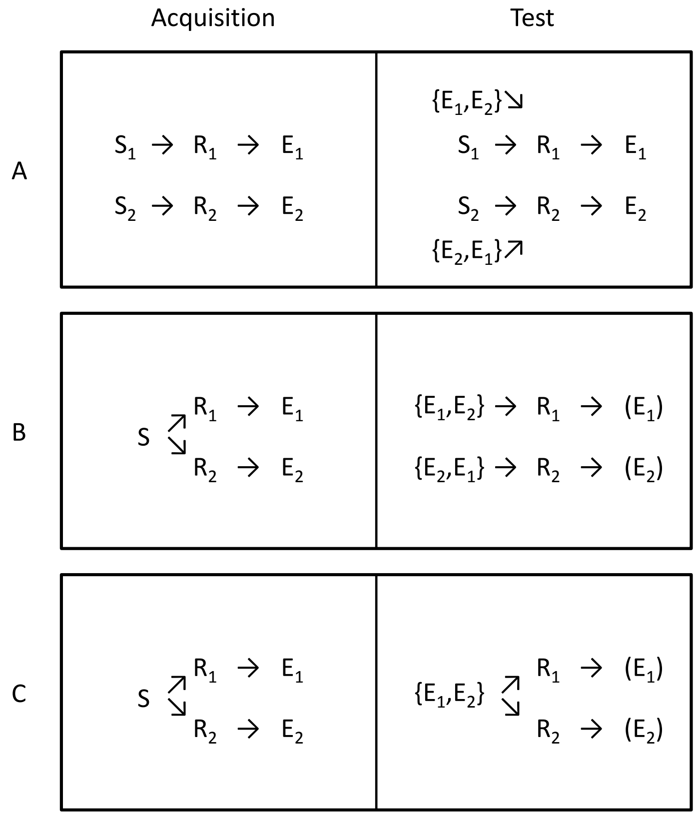


Figure 2: Experimental designs to investigate the acquisition of bidirectional action-effect associations. Note: S=Stimulus; R=Response; E=Effect.

Both of these questions have been addressed by adopting experimental paradigms from animal research (see Elsner & Hommel, 2001). In all versions, participants carry out particular actions, such as a left or right keypress (R_1 and R_2), and are presented with novel sensory effects of these actions (E_1 and E_2), say, a low-pitched tone whenever they press the left key ($R_1 \rightarrow E_1$) and a high-pitched tone whenever they press the right key ($R_2 \rightarrow E_2$). Which key they are to press in the acquisition phase may be signaled by a discriminative stimulus (S_1 and S_2), as indicated in panel A of Figure 2, or be left to their own choice (see panels B and C). The general idea is that the contingency and temporal contiguity between responses and action effects creates bidirectional associations between their cognitive representations. If so, presenting an action-effect stimulus should prime the action that had produced that stimulus in the acquisition phase.

Whether this is the case is tested in a subsequent test phase. In the study of Hommel (1996a), participants were still carrying out responses to stimuli and the responses were still producing their effects (see panel A). However, the actual stimuli were accompanied by task-irrelevant distractors that were similar to or identical with the effect of one of the actions. As expected, participants were faster to respond if the distractor was related to the effect of the correct response than if it was related to the effect of the incorrect alternative response. The disadvantage of this design is that this type of priming effect might reflect stimulus-effect learning, response-effect learning, or both. To distinguish between these two possibilities, Elsner and Hommel (2001) created two groups of participants, that both went through the same acquisition phase (see panel B). Both groups were now to respond to stimuli that were previously used as action effects, but the mapping of effect stimuli to responses differed. In one group, participants carried out the responses to exactly the same stimuli that these responses had produced in the acquisition phase (e.g., $E_1 \rightarrow R_1$ after having experienced $R_1 \rightarrow E_1$, $R_2 \rightarrow E_2$), so that these participants should benefit from the hypothetical bidirectional action-effect associations. In the second group, participants received the reverse mapping, so that they now would respond to a previous effect stimulus with the response that previously produced the alternative action effect (e.g., $E_1 \rightarrow R_2$ after having experienced $R_1 \rightarrow E_1$, $R_2 \rightarrow E_2$). As expected, participants were much faster in the first than the second group, which not only suggests that people acquire action-effect associations on the fly (as all action effects in the acquisition phase were task-irrelevant and learning them was not encouraged), but also that these associations are bidirectional—so that previous consequences of actions can now serve as effective primes of these actions.

The same conclusion can be drawn from another version of the action-effect learning paradigm. Elsner and Hommel (2001) also had participants carry out a free-choice task after undergoing the acquisition phase. Now participants were presented with randomly selected action effects, which merely served as a trigger to carry out a self-chosen response (see panel C). Ideomotor reasoning would suggest that the acquired action-effect associations would bias the selection towards the actions that were primed by the trigger stimulus. In other words, participants were expected to prefer the selection of the action that was previously producing the stimulus that was now serving as a trigger. This is exactly what Elsner and Hommel observed, irrespective of whether actions still produced their effects in the test case or not.

Numerous studies from various labs have demonstrated the spontaneous acquisition of associations between various sorts of actions and action-contingent events from various sensory modalities (for a recent overview, see Hommel, 2009), suggesting that any kind of perceivable action effect can be learned. Elsner and Hommel (2004) provided evidence that the limits of action-effect learning are the same as for associative learning in general. In their study, participants acquired action-effect associations only if the temporal gap between action and effect was no longer than 1 second and if the relationship between action and effect was either highly contingent or if the effect occurred with a high frequency. Interestingly, the same limiting criteria have been reported from conditioning experiments in non-human animals, suggesting that the underlying integration processes are similar (see Elsner & Hommel, 2004). Likewise, action-effect associations are not (much) affected by extinction, which is another characteristic that has also been reported from animal research (Rescorla, 1993). However, acquisition seems to set in much faster in humans than in other animals: Dutzi and Hommel (2009) reported that free choice is reliable biased towards the action that previously had produced the current trigger stimulus after just one previous action-effect pairing.

Given the considerable developmental implications of ideomotor theory, it was important to demonstrate that its predictions do not only hold for adults but for children and infants as well. Eenshuistra, Weidema, and Hommel (2004) translated the Elsner and Hommel (2001) paradigm into a child-friendly version and basically found the same effects in four- and seven-year-olds. In addition, four-year-olds exhibited a rather dramatic effect in the error rates (see also Kray, Eenshuistra, Kerstner, Weidema & Hommel, 2006), which suggested that at least some children were close to or entirely unable to carry out an action to a stimulus that previously was produced by the alternative action. In other words, the behavior of the younger children seemed to be directly driven by (the representations of) action effects. Spontaneous and bidirectional action-effect integration could also be demonstrated in infants as young as nine months of age (Verschoor, Weidema, Biro & Hommel, 2010).

The observation that agents are picking up action effects even under conditions that do not provide any reward or benefit for attending to and learning them does not fit with suggestions of developmental researchers that intentionality precedes action-effect acquisition (Rochat, 2001) but, rather, support the ideomotor suggestion that intentionality emerges through experience. In other words, our action intentions are derived from the experience of options, rather than genetically given. However, even though this scenario would elegantly address the long-standing philosophical question of where intentions come from (Lotze, 1852), it has been challenged only recently. Herwig, Prinz, and Waszak (2007) compared two versions of action-effect acquisition paradigms: a forced-choice version in which, in the acquisition phase, responses were signaled by discriminative stimuli (as in panel A of Figure 2) and a free-choice version in which participants were only presented with a trigger and could select one of the two possible responses as they wanted (panel B). In the subsequent test phase (which was as in panel B) reliable effects of action-effect learning were obtained after free-choice practice but not after forced-choice practice. The authors concluded that action-effect integration relies on the degree of intentionality: In the forced-choice acquisition condition people merely react to environmental demands, which does not lead to effective action-effect learning. In contrast, in the free-choice acquisition condition people carry out actions to produce environmental effects and, therefore, consider action effects sufficiently relevant to acquire them.

If correct, this interpretation would undermine ideomotor theory for the most part. If action-effect integration would presuppose, rather than explain the emergence of intentional action control, the applicability and theoretical range of ideomotor theory would be drastically narrowed and the major strength of the theory be eliminated. However, the intentionality hypothesis suggested by Herwig and colleagues is not without problems and alternative interpretations are tenable. For one, reliable action-effect learning with forced-choice acquisition practice had been demonstrated before (Hommel, 1993, 1996a; Kunde et al., 2002), which does not seem to fit with the assumption that intentionality is necessary for action-effect integration and/or the assumption that stimulus-driven action is not intentional. For another, it may be that the reliance of performance on, and the resulting maintenance of stimulus-response associations competes with the retrieval of action-effect associations. This possibility is suggested by a recent study of Pfister, Kiesel, and Hoffmann (2011). These authors replicated the basic design of Herwig et al. (2007) but replaced the forced-choice task in the *test* phase by a free-choice task. Reliable evidence for action-effect integration was obtained and the size of this effect was no different from that observed after free-choice practice. This pattern does not support the assumption that the mode of action or intentionality during acquisition matters but, rather, is consistent with ideomotor reasoning.

To conclude, there is converging evidence that people at all ages acquire the sensory effects of their actions spontaneously and on-the-fly. Codes of these action effects become associated with the motor patterns that originally led to the activation of these codes. The resulting associations are bidirectional, so that the intentional or non-intentional reactivation of action-effect representations leads to the priming of the associated motor pattern.

Do agents anticipate effects of their actions?

Ideomotor theory assumes that actions are selected by anticipating their sensory consequences. This anticipation entails the activation of the representations of these consequences, which spread activation to the associated motor patterns. Incidentally acquired bidirectional associations between motor patterns and representations of sensory action effects provide sufficient knowledge for anticipating action effects, but the availability of information does not necessarily imply its effective use. Accordingly, we need to ask whether agents are actively engaging in anticipating the effect of their actions.

A first hint to at least some sort of active anticipation can be taken from research on the planning of complex and sequential actions. Numerous studies have shown that the time people take to begin an action or the first element of an action sequence increases with the complexity of the movement(s) (Henry &. Rogers, 1960) and the number of movement parameters to be controlled (Rosenbaum, 1980), suggesting that selecting and planning a movement takes the entire action into consideration. More direct evidence for the active anticipation of the sensory consequences of actions comes from Hommel (1993). Participants in the study carried out a task that was expected to produce a Simon effect (Simon & Rudell, 1967; for reviews, see Hommel, 2011; Proctor, 2011): they carried out left and right keypress responses to the pitch of a tone that was randomly presented through a loudspeaker on the left or right. Even though the tone location was task-irrelevant, responses were faster if the response location matched the location of the stimulus tone—the Simon effect. Interestingly, in one of the conditions pressing a key produced a light flash on the opposite side, so that a left keypress triggered a right visual action effect and a right keypress a left action effect. When participants were instructed to “press the left/right key in response to the low/high pitch of the tone”, the standard Simon effect was replicated: a key was pressed faster if its location corresponded to that of the stimulus tone. However, when participants were instructed to “flash the right/left light in response to the low/high pitch of the tone”, the effect reversed: now a key was pressed faster if its location did not correspond to the tone location! This means that participants must have coded their responses with respect to the sensory effect they intended to produce, so that intending to press a left key rendered the cognitive representation of the action “left” but doing the same in order to flash a right light rendered it a “right” action.

Converging evidence for the active anticipation of action effects comes from studies on the so-called action-effect compatibility. As observed by Kunde (2001), spatially defined actions are initiated faster if they are followed by visual action effects that appear in the same relative location. Along the same lines, Koch and Kunde (2002) reported that participants are faster to vocally respond with color names if the responses trigger the visual presentation of the corresponding color word or color rather than an incongruent color word or color. Given that in both of these studies the action effects were presented long after the response was initiated, the reaction time effects must reflect some sort of anticipation of the to-be-expected sensory consequences of the to-be-selected action.

Further evidence for active anticipation was provided by two recent ERP studies. Waszak and Herwig (2007) had participants acquire keypress-pitch associations before presenting them with an auditory oddball task, in which standard tones and infrequent deviants appeared. Auditory deviants produced a P3 component that was more pronounced when preceded by the response that was associated with the standard. Band, van Steenbergen, Ridderinkhof, Falkenstein, and Hommel (2009) had participants perform a probabilistic learning task, in which some keypresses triggered tones of a particular pitch in 80% of the trials and of another pitch in the remaining trials. Experiencing a less frequent action effect generated a so-called feedback-related negativity (Miltner, Braun & Coles, 1997), an ERP component that is commonly seen when negative feedback is presented. Both studies suggest that carrying out a particular response is associated with the expectation that the corresponding sensory consequences appear.

Finally, in a recent fMRI study (Kühn, Keizer, Rombouts & Hommel, 2011), participants were to switch between a manual binary-choice task (pressing a left vs. right key) and a facial binary-choice task (assuming a kissing vs. grinning expression). The type of action was precued on a trial-by-trial basis and the preparation interval between cue and target presentation was analysed. Preparing for manual action activated hand-related areas of the motor cortex and the extrastriate body area, which is known to mediate the perception of body parts. In contrast, preparing for facial action activated face-related motor areas and the fusiform face area, known to mediate face perception. This shows that preparing for a particular type of action goes along with activating the cortical area that process the sensory consequences that this type of action produces—long before these consequences are actually perceived.

Do action-effect anticipations control the action?

We have seen that there is increasing evidence that people do not only acquire but actively use knowledge relating the motor patterns driving their actions to representations of the sensory consequences these actions are likely to have. However, it is possible that active anticipation serves other purposes than action control, so that we need to ask whether action-effect anticipation and action control are directly connected. Hence, do we have evidence that anticipation plays a functional role in selecting and controlling actions?

An interesting hint to such a role can be taken from research on what has become to be known as Hick's law—which refers to the observation that reaction time increases with the number of possible response alternatives (for a recent review, see Schneider & Anderson, 2011). Leonard (1959) reported an interesting exception to this law with tactile stimulation, which allowed particularly efficient responding independently of the number of alternatives. Given that Hick's law is commonly taken to reflect greater demands on, or more competition related to response selection as more action representations compete for execution (see Schneider & Anderson, 2011), Leonard's observation suggests that response selection can be successfully circumvented with tactile stimulation. In a follow-up study, ten Hoopen, Akerboom, and Raaymakers (1982) found that the deviation from Hick's law is particularly pronounced with tactile stimulation at a frequency that fits best with the sensitivity of the tactile finger receptors. If we consider that tactile, as compared to visual or auditory, stimulation maximizes ideomotor compatibility (i.e., the similarity between the sensory features of the stimulus and the sensory features of the expected action effect: see Greenwald, 1970), this pattern of findings fits exactly with expectations from ideomotor theory. Indeed, if selecting an action involves the anticipation of its perceptual outcome, the selection process should be facilitated more the more sensory features the presented target stimulus shares with this outcome.

If ideomotor compatibility facilitates response selection by providing the opportunity to delegate the selection process to the stimulus, one would expect that the choice of ideomotor-compatible stimuli helps to reduce or even eliminate processing bottlenecks that are related to response selection. Applying this logic, Greenwald (2003; Greenwald & Shulman, 1972) showed that making stimulus-response relationships ideomotor-compatible leads to a dramatic reduction or the elimination of the commonly very substantial processing costs associated with processing two tasks at the same time. Even though it is still debated how large and how general this effect is (e.g., Lien, Proctor & Allen, 2002), it is clear that response selection can be drastically facilitated through ideomotor compatibility. This provides evidence that the sensory consequences of performing an action play a role when selecting it for execution, which suggests that response selection considers codes that represent and, thus, predict these consequences.

Further evidence along these lines comes from Kunde, Hoffmann, and Zellmann (2002). They had participants carry out a task in which one of four possible responses was to be performed in each trial. A precue informed the participant about the correct response with a high validity so that, unsurprisingly, reaction times were faster if the cue was valid than if it was invalid. Importantly, the responses triggered auditory action effects according to a 2:1 mapping, so that two responses shared the same auditory action effect. Results showed that responses following an invalid cue were faster if they shared their auditory effect with the cued response, which suggests that switching from one (primed or preselected) response to another was easier if the to-be-expected action effect was the same. Clearly, this suggests that effect anticipations are considered in response selection. This conclusion has received further support from Paelecke and Kunde (2007). They had participants carry out two tasks and varied the time interval between the two stimuli (the stimulus-onset asynchrony) as well as the compatibility between responses and their experimentally-induced sensory effects. Effects of the time interval and compatibility combined in an additive fashion, which according to the so-called locus-of-slack logic (Pashler & Johnston, 1989) suggests that action-effect compatibility affects response selection.

If representations of action effects are related to the selection and activation of associated responses, one would predict that presenting a stimulus that resembles or is identical with a previously acquired action effect leads to the activation of brain areas that are involved in the motoric realization of actions. To test that, Elsner et al. (2002) presented participants with an acquisition phase as shown in panel B of Figure 2 before placing them in a PET scanner. During the scans, participants were monitoring a stream of auditory stimuli for a target sound, which was arranged to never appear during the actual scan. The auditory stream contained various portions of previously acquired action-effect tones, which allowed identifying brain areas whose activation varied systematically with the number of effect tones in the stream. Two areas were identified: the supplementary motor area, which is assumed to house executable action plans, and the right hippocampus, which was likely to link the auditory information to motor structures. A more recent fMRI study could replicate this observation in a similar, but more sensitive design (Melcher, Weidema, Eenshuistra, Hommel & Gruber, 2008). Taken together, these observations provide strong evidence that representations of action effects are not only related to the motor patterns that generate them, but that these representations are affecting and playing a functional role in response selection—most likely through priming the action that is associated with the intended effect.

Note that this scenario leaves open how a particular action effect becomes “intended”. Even though this is an interesting issue, ideomotor theory is a cognitive approach that aims to explain how intended effects are translated into overt movement but not a motivational approach that explains why that particular effect was chosen to control the action. Along the lines of de Wit and Dickinson (2009), one might speculate that what we call an action intention is simply the action effect that is presently considered the most promising in terms of expected reward. In any case, however, it is certainly true that hitherto motivational issues are insufficiently reflected in ideomotor theorizing.

What aspects of actions do action-effect anticipations control?

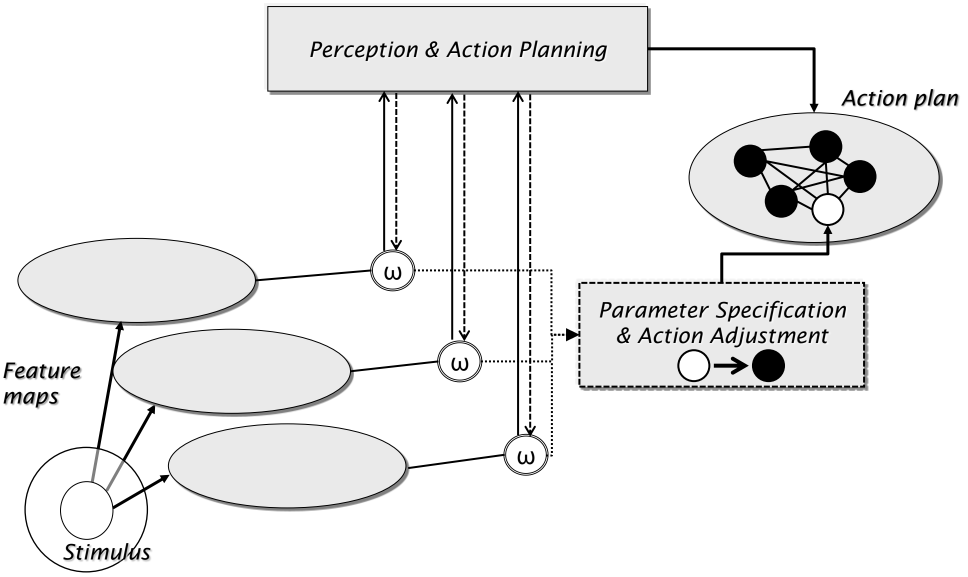
The scenario that ideomotor theory suggests for how actions are controlled has a strong feedforward flavor: the outcome of a planned action is predicted in advance and, even though some final check whether the predicted effect actually occurred seems to take place (Band et al., 2009), there does not seem to be much room or need for continuous online control. It is obvious that such a scenario is insufficient to account for all aspects of action control or, more specifically, for action control at all levels. Consider, for instance, the study of Prablanc and Pélisson (1990). Participants were presented with a spatially defined target that they were to touch with their index finger. Unbeknownst to the participants, the target was sometimes slightly moved while they moved their eyes, so that no participant was able to detect the movement. Even if the target was moved after the onset of the finger movement, the finger always moved straight to the final target location and it did so without any hesitation or temporal delay.

Observations of this sort and many other, related findings (for a review, see Milner & Goodale, 1995) strongly suggest that action control takes place at several levels. At one level, the general purpose and major outcome of an action are determined and general features of the actions are planned ahead (i.e., offline) while, at a lower level, online adjustments to environmental changes can be made as long as the action is underway (Glover, 2004; Hommel et al., 2001b). Action control thus integrates feedforward and feedback mechanisms. The feedforward mechanism determines the relevant aspects of the action and those portions of the sensory effects that the agent actually intends to produce, whereas the feedback mechanism provides the remaining parameters based on the current environmental state of affairs. Obviously, ideomotor theory has not much to contribute to the lower-level feedback mechanism but focuses on the higher-level feedforward mechanism. This particular focus is a logical consequence of the theory's historical heritage. As discussed already, the originators of ideomotor theory were interested in the link between conscious states and motor activity, and their main methods were logical reasoning and introspection. According to Milner and Goodale (1995) and Glover (2004), consciousness gets access to higher-level processes (or their products) only while lower-level online processes are not consciously accessible in principle. Considering this asymmetry, it thus makes sense that ideomotor theory is more interested in the former than the latter.

According to the original proposal of Milner and Goodale (1995), higher-level and lower-level mechanisms operate independently, a theoretical choice that, among other things, reflects these authors’ claim that higher-level processes are restricted to perception while lower-level mechanisms are devoted to action control. This conception ran into a number of problems however. The problems that are of major interest for present purposes are theoretical. As voluntary action can be defined as carrying out movements in order to reach a particular goal, it is essential that action control comprises of some sort of anticipation. As discussed in the introduction, aiming for a particular goal implies the anticipation of a particular effect, as well as the expectation that this effect will be produced by a particular type of movement. Whether this information is consciously represented or not need not be important but it is clear that the information goes beyond the present state of affairs—a kind of projection into the future. It is difficult to see how this projection could be made without any memory about past performance, action-effect relationships, the relative efficiency of actions, and so forth. Hence, action planning relies on memory (Dixon & Glover, 2004). However, the original action-control pathway that Milner and Goodale (1995) envisioned had no access to long-term memory whatsoever, which raises the question how the pathway could be configured to choose one over another action, process action-relevant information and ignore irrelevant information, and consider the final action goal when adjusting the ongoing action to environmental changes.

The alternative suggested by Glover (2004) and Hommel et al. (2001b) is to keep the distinction between high-level offline processes and low-level online processes but to include action planning as part of a higher processing level. This choice does not only deal with a number of empirical problems with the original scenario (see Glover, 2004) but also acknowledges the obvious fact that at least some aspects of action planning are consciously accessible (Hommel, 2007). Moreover, it provides the opportunity to address an important gap in the original Milner and Goodale (1995) story, namely, the question how the operation of lower-level online mechanisms is actually controlled and adjusted to the current task goal. Figure 3 sketches a recent suggestion of how this question could be addressed (Hommel, 2010). The basic idea is that high-level processes (the ideomotor level, as it were) controls lower-level sensorimotor processes by providing the basic structure of the action plan and by increasing the gain of output from sensory feature maps that provide action-relevant information (Wykowska, Schubö & Hommel, 2009). Feature maps are assumed to code a given stimulus on different feature dimensions, such as shape, color, and orientation (Treisman, 1988) and to deliver that information to both higher-level processes busy with perception and action planning and lower-level processes that are continuously feeding environmental information into the sensorimotor loop. The perception-action system can increase the weight of information coming from action-relevant feature maps, such as the shape map in the context of a grasping action or the location map in the context of a pointing action. This increase will lead to a greater dominance of the corresponding information in the lower-level sensorimotor loop, so that the perception-action system can be considered to control the “attention” of the sensorimotor system. Moreover, the perception-action system will specify the goal-relevant features of the action, such as the object to be grasped or to be pointed to, but leave less relevant features, such as movement duration or hand posture (which of course may also be relevant under different goals), to be filled by the sensorimotor system.

Figure 3: Sketch of a process model of the interaction between the offline-operating ideomotor perception-action system and the online-operating sensorimotor loop (see Hommel, 2010).



This scenario implies interesting predictions that have been confirmed in a number of recent studies. Fagioli, Hommel, and Schubotz (2007) had participants plan (but not yet carry out) a reaching or grasping action before presenting them with a sequence of visual stimuli that did or did not include a size or location oddball. When participants had prepared a grasping action, they were faster to detect a size than a location oddball, while preparing a pointing action resulted in better performance for location than size oddballs. In other words, preparing an action facilitated the detection of visual stimulus features that can be assumed to provide the most relevant information for driving the sensorimotor loop underlying this action: the size feature for grasping and the location feature for pointing. The same conclusion is suggested by the finding of Wykowska et al. (2009) that preparing an action facilitates visual search for a pop-up target if the target is defined by an action-related dimension: size-defined targets benefit from preparing a grasping action whereas luminance-defined targets benefit from preparing a pointing action.

As discussed in the context of the potency of ideomotor-compatible stimuli to facilitate or even circumvent endogenous action-selection processes, ideomotor theory suggests that external stimulus information can help or even replace endogenous action planning to the degree that it activates representations of (previously acquired) action effects. Access to motor patterns is assumed to be mediated through the activation of action-effect representations and it does not matter in principle whether this activation stems from entirely endogenous processes or from external stimulation—even though in healthy adults activation from the former will commonly be much stronger and more dominant than activation from the latter. If we combine this assumption with the idea that activating an action plan biases attention towards action-related features, it should be possible to achieve this bias even in the absence of endogenous action planning. To test that, Fagioli, Ferlazzo, and Hommel (2007) use the same task as Fagioli, Hommel, and Schubotz (2007) but, instead of requiring participants to actively plan a grasping or pointing movement, presented them with short video clips that showed another person carrying out a grasping or reaching movement. Although these videos were not relevant to the task and did not predict the stimulus sequences or the correct response, participants were faster to detect size oddballs after having seen a grasping movement and location oddballs after having seen a reaching movement.

The representation of actions and agents

Ideomotor theory assumes that actions are represented in terms of their perceptual effects, which renders cognitive action representations perceptually grounded in the sense of Harnad (1990). Interestingly, the same holds for representations of the agent him/herself. According to the theory it is only through the repeated experience of efficacy and the acquisition of action-effect associations that a random mover turns into an intentional agent. As actions are merely represented in terms of their re-afference, so is the agent—one exists by virtue of making a perceptual difference. This perspective is very close to David Hume's approach to the representation of self. "I never can catch myself at any time without a perception," Hume (1739/1969, Book I, Part 4, Section 6) says, "and never can observe any thing but the perception. When my perceptions are remov'd for any time, as by sound sleep; so long am I insensible of myself, and may truly be said not to exist." This perceptual take on the concept of the self—the minimal self in the terminology of Gallagher (2000)—suggests that people, including oneself, are cognitively represented just like any other event: in terms of the perceptual effects they create. The cognitive representation of oneself would thus comprise of a network of codes that refer to the sensory effects one has perceived to produce. Interestingly, a recent series of experiments on the so-called social Simon effect has provided evidence for this kind of perceptual grounding of the self.

As mentioned already, the standard Simon effect is observed when an agent carries out spatially defined responses to non-spatial stimulus features appearing at randomly varying locations. If, for instance, a participant is to press a left and right key in response to a green and red stimulus, respectively, s/he will be faster and more accurate if the green stimulus happens to appear on the left side and the red stimulus on the right side (cf., Simon & Rudell, 1967). If this task is turned into a go-nogo task by having the participant operating only one of the two keys, the Simon effect is drastically reduced or even disappears (Hommel, 1996b), presumably because left and right responses need no longer be discriminated and spatially coded. As a consequence, the response code does no longer match or mismatch with left or right stimuli, so that spatial stimulus-response relations no longer matter. Interestingly, however, a full-blown Simon effect is obtained if the other key is operated by another person (Sebanz, Knoblich & Prinz, 2003), which has been taken to suggest that other people's actions are spontaneously co-represented and to reflect “the social nature of perception and action” (Knoblich & Sebanz, 2006).

The ideomotor approach provides an alternative and mechanistically more concrete interpretation of this observation. If the cognitive representations of “me” and “other” mainly consist of perceptual codes, there is no qualitative, but only a gradual difference between “me” and another co-agent. This difference is more pronounced than the social approach of Knoblich and Sebanz (2006) would have it, as some dissimilarity and therefore the means to discriminate between “me” and “other” always remain. Moreover, in contrast to the social approach this perceptual-self hypothesis suggests that the degree of dissimilarity and, thus, of self-other discrimination can vary as a function of the number of features shared between me and a co-agent.

First evidence that the social Simon effect can vary as a function of the perceived relationship between co-actors was provided by Hommel, Colzato, and van den Wildenberg (2009), who obtained a full-blown effect if participants worked together with a co-actor that was as friendly as they were themselves but no effect if they worked with an unfriendly, aggressive co-actor. Further evidence was reported by Hommel, van den Wildenberg, and Colzato (2011), who tried to modify the perceptual integration of self and other by means of Gestalt laws. Pairs of participants were performing a social Simon task side-by-side with an open or closed curtain between them (so to manipulate the Gestalt law of common region) and while holding or not holding the same pen (so to manipulate the Gestalt law of connectedness). As expected, the social Simon effect varied as a function of perceptual relatedness: it was reduced if the curtain was closed and increased by holding the same pen. No effect was obtained if neither manipulation supported perceptual grouping, which suggests that self- and other-perception are essential for co-representation to materialize. Even though this issue calls for more research, the available observations provide support for the ideomotor suggestion that the cognitive representations of self and other are grounded in perceptual experience.

Conclusion

Taken altogether, we can conclude that people acquire bidirectional action-effect associations spontaneously, make active use of the information to anticipate action outcomes, and select suitable actions through this anticipatory process—just as claimed by the ideomotor approach to action control. Ideomotor action control specifies the goal-related, intended aspects of actions and sets the stage for low-level online processes that take care of the further adjustments of ongoing actions to the environmental conditions. The ideomotor approach implies that actions are cognitively represented in terms of their sensory consequences and action goals consider these consequences in formulating intended action outcomes. Hence, people do not directly set up motor patterns to carry out movements, nor do stimuli directly trigger such patterns. Instead, action planning seems to operate on perceptual representations that act as retrieval cues for goals and motor activity. In other words, action goals and action plans are no abstract mental constructions that truly perceptually grounded (cf., Harnad, 1990). From this perspective, perception serves action control and one may speculate that the mechanisms mankind has developed to control perceptual processing—attention, that is—are a mere phylogenetic byproduct of the need to optimize action control and the interaction between high-level planning and low-level sensorimotor processing in particular (Hommel, 2010). In that sense Goethe might have been right: in the beginning was the act.

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