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# Goal-Directed Actions

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## Abstract and Keywords

Personal causation relies on translating goals into goal-directed behavior. This chapter addresses how humans generate a goal-directed behavior, that is, how they initiate and control intentional, goal-directed actions. In particular, it discusses how anticipated action effects are integrated with motor patterns, so to guide future effect-driven actions, and how action intentions struggle with overlearned habits. It argues that intentional and conscious processes typically precede, rather than accompany, intentional actions, and that the experience of personal agency and the identification of action errors are based on a comparison between expected and actual action effects. A final outlook addresses the implications of increasing insight into cognitive embodiment and of increasing interdisciplinarity for the study of human action control and personal causation.

Keywords: intentional action, human action control, habit, action, agency, consciousness

As various contributions to this *Handbook* discuss, humans can reason about cause–effect relationships in rather abstract ways, but they can also extract information about such relationships from visual events they perceive (White, Chapter 14 in this volume). And yet, arguably the most direct experience of causality emerges from one's own action. It is through actions that we can change our environment and express ourselves from the first months of our lives (Rochat, 2001). Actions also have a social function that provides the attentive observer with information about mental causation, that is, about the fact that human actions are caused by, and thus express, internal goals. Given that we cannot directly access the goals of other individuals, their actions are often the only clues to their goals we have. Some authors have even argued that the same applies to ourselves: we may often learn about our own goals only by observing the actions they generate (Wegner, 2002). In any case, in order to understand how personal causation works, we need to understand how goals translate into goal-directed behavior. Accordingly, this chapter addresses how humans initiate and control intentional, goal-directed actions. In

some sense, the term “goal-directed action” is a pleonasm, because actions are considered to differ from mere movements in their goal-directedness—a characteristic that mere movements do not possess. Hence, at least overt actions can be considered goal-directed movements, which means that the term “action” is sufficient to express goal-directedness. Covert, purely mental actions (e.g., O’Brien & Soteriou, 2009) are more difficult to define. As mental actions are arguably derived from, and thus are simulations of, overt actions (e.g., Grafton, 2009; Vygotsky, 1934/1986), I will restrict the discussions in this chapter to overt actions and the way they are controlled.

In any case, in order to meet the criterion of being directed toward a goal, a given process would need to rely and be conditional on some sort of knowledge about the relationship between this process and some future event, and it would need to be activated as the consequence or side effect of activating (p. 266) a representation of this future event (Dickinson & Balleine, 1994). Among other things, this means that, as William James (1890, p. 487) has put it, “… if, in voluntary action properly so-called, the act must be foreseen, it follows that no creature not endowed with divinatory power can perform an act voluntarily for the first time.” That is, before someone can carry out a goal-directed process, he or she must have acquired some knowledge about the fact that a particular event—the representation of which must be included in the goal representation—can in fact be created by carrying out that process. Unless we assume that humans are born with a particular set of concrete goals—a possibility for which no empirical support has been provided so far—learning about which processes can lead to which effects in the internal or external world must precede the ability to perform goal-directed activities.

# From Movement to Action

The importance of many basic cognitive abilities often becomes clear only if they are impaired, declining, or absent—be it through degeneration, accidents, or the lack of sufficient development. Particularly instructive for a deeper understanding of goal-directed action is the behavior of a newborn child. This behavior shows frequent and dramatic changes of activity levels, rapid successions of phases of highest degrees of liveliness and sleepiness. But even the most active phases show very little, if any, expression of what we call goal-directed action. Instead, we can see numerous examples of relatively rigid reflexes, including the rooting and sucking reflexes that help the child to engage in breastfeeding, the stepping reflex that facilitates the acquisition of walking, and the grasping reflex that supports the exploration of the object world. As the frontal lobe of the human brain—which is required to generate more complex action plans—develops, almost all basic reflexes disappear, but only after having left many important traces of the child’s sensorimotor experience with its environment.

According to ideomotor theory (Harless, 1861; Hommel, 2009; James, 1890; Lotze, 1852; for an overview, see Stock & Stock, 2004) and Piaget's (1946) approach to cognitive development, sensorimotor interactions allow the child to acquire information about the contingencies between its movements and their impact on the environment. Storing these contingencies is considered to be the first step in generating a cognitive representation of one's world, with an emphasis on one's own opportunities to actively change it. Accordingly, these contingencies provide the database necessary to generate goal-directed action (i.e., movements that are driven by some anticipation about their outcome).

Turning movements into actions thus requires some sort of anticipation of the likely outcomes of a given movement and a selection of the movement based on this anticipation (two aspects that I will discuss in more detail under "Action Selection and Prediction"). The ability to select a movement based on its likely outcomes requires the integration of movement codes (i.e., cognitive/neural codes that generate movements) and action-effect codes (i.e., cognitive/neural codes that represent to-be-expected movement outcomes). According to ideomotor theory, this integration emerges through Hebbian learning (what fires together wires together): the agent starts with some motor babbling (the execution of more or less random movements or reflexes), registers the sensory feedback that these movements generate, and associates the motor patterns underlying the movements with representations of the feedback. The resulting associations are bidirectional, so that from now on the activation of the movement leads to an anticipation of its outcome (i.e., to the priming of the outcome representations) and the activation of the outcome representations can activate the movement pattern resulting in such outcomes. Hence, the agent can now intentionally activate particular movements by simply activating the representations of wanted outcomes (e.g., by actively imagining them). In other words, ideas can now lead to motor behavior, and movements become goal-directed actions.

The recent years have provided considerable evidence supporting this scenario (for overviews, see Hommel, 2009; Shin, Proctor, & Capaldi, 2010). Infants, children, and adults were shown to pick up action-effect contingencies on the fly, irrespective of the current action goal, and to create bidirectional associations between the underlying movement patterns in the representations of the effects (e.g., Elsner & Hommel, 2001; Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006; Verschoor, Weidema, Biro, & Hommel, 2010; for an overview, see Hommel, 2009; Hommel & Elsner, 2009). Representations of action effects are not just acquired, they can also be shown to be involved in action selection. For instance, presenting people with action effects before or during action selection interferes with selecting an action producing another effect (Hommel, 1996) and selecting actions with mutually incompatible action effects (such as pressing the left key to produce an event on the right (p. 267) side) is less efficient than selecting actions with compatible effects (Kunde, 2001). This suggests that the sensory consequences of actions are considered when and in the process of selecting them. This is consistent with findings from brain-imaging studies, which show that presenting people with possible action effects tends to activate the action producing them (Elsner at al.,

2002; Melcher et al., 2008) and that preparing for particular actions leads to the activation of brain areas that are involved in perceiving the sensory effects of these actions (Kühn, Keizer, Rombouts, & Hommel, 2011).

# Action and Habit

Heraclitus reminded us that we cannot step into the same river twice, which means that events that look the same at the surface often keep changing in the underlying structure. This certainly holds for actions, which keep changing in character and the way they are controlled with every execution. What will become a goal-directed action often begins with rather uncoordinated, sometimes explorative movements. This is true for the motor babbling of infants, which is often only constrained by the available reflexes and the activity level of the agent, but it is also true for the adult learner of a particular skill. The first moves of a beginning dancer or skier are only weakly hinting at the intended direction, and the many degrees of freedom of the limbs are often strategically “frozen” to reduce the demands on control processes (Bernstein, 1967). As the motor adjustments become more efficient, predicted and actual action effects become more similar which, as described earlier, turns movement into actual action.

But the changes in controlling actions do not end here. Exercising an action is known to reduce its control demands and to free up cognitive resources: the action or skill becomes automatic. “Automaticity” is a rather problematic term that has defeated all attempts to define it properly (Bargh, 1997; Hommel, 2000). Originally, it was intended to indicate the lack of endogenous control over the behavior that highly overlearned stimuli are able to trigger (Shiffrin & Schneider, 1977). A famous example is the Stroop effect (Stroop, 1935): the fact that people find it difficult to ignore incongruent meanings of color words (the color of which they are intending to name) has been taken to suggest the automaticity of word reading. Another example is the Simon effect (Simon & Rudell, 1967): the finding that people are slower and less accurate in responding to stimuli the location of which does not correspond to the location of the correct response has been taken to imply automaticity of location processing.

However, there are reasons to doubt that action-in-using tendencies are truly automatic in the original sense (Hommel, 2000). For instance, participants in a Stroop task are being asked to respond to words and to articulate color names, which implies that they have established a cognitive set that is likely to draw attention to color names. Accordingly, what seems to be an automatic process is likely to reflect the consequences of intentional task preparation. Indeed, it has been suggested that action control rarely operates online (Bargh, 1989; Exner, 1879). Rather, people intentionally prepare possible actions and delegate their control to external stimuli—which can produce response conflict under very artificial conditions like the Stroop task, but frees up precious cognitive resources to “look ahead” even further.

Nevertheless, it is true that overlearned actions become habits, which goes hand in hand with a change in the way they are controlled (Gershman, Chapter 17 in this volume). For instance, overlearned actions tend to be efficient, to occur outside of awareness, and to be stimulus-driven and ballistic (i.e., difficult to stop once they are triggered) (Bargh, 1994). Stimulus-driven actions seem to be mediated by different neural structures than those that mediate more goal-driven actions (Passingham, 1997) and they are less sensitive to sensory action effects (Herwig, Prinz, & Waszak, 2007) and reward (e.g., Watson, Wiers, Hommel, & de Wit, 2014).

The lack of reward-sensitivity of overlearned actions has been taken to imply that they no longer should be considered true goal-directed actions (Dickinson & Balleine, 2009). According to this perspective, the desire to realize a particular outcome is a defining criterion of goal-directed actions, and the lack of sensitivity to action-contingent reward must be considered a lack of desire. While this account is consistent with some philosophical definitions of human action, it is rather problematic if applied to systems-level accounts of action control. For instance, there is evidence that even overlearned actions are based on outcome anticipations: Band et al. (2009) had participants engage in a complicated stimulus–response mapping task, in which each of the four responses produced a particular auditory outcome. Each response produced one specific outcome in the majority of the trials, but another outcome, or a number of outcomes, in the remaining trials. Even though the outcomes (p. 268) were entirely irrelevant to the task, actions that produced unexpected outcomes triggered electrophysiological components similar to the feedback-related negativity that is observed if agents are told that their action was incorrect. This suggests that even stimulus-driven actions are accompanied by anticipations about their consequences, which makes them goal-directed. Moreover, recent findings provide evidence that, consistent with White (1959), the mere production of particular action outcomes is rewarding (Eitam, Kennedy, & Higgins, 2013), which suggests that the elimination of external reward does not necessarily imply the absence of any reward. In particular, the available evidence seems to suggest that the main reward for acquiring an action comes from the match between anticipation and actual outcome (Wolpert & Ghahramani, 2000), rather than receiving some added external reinforcers. If so, goal-directed actions are producing their own reward to the degree that the intended, or at least anticipated effect is actually produced.

# Preparation and Execution

The previous section may be taken to imply that a given action can only be either intentional/effortful or automatic, but not both. However, while this may be true for one given act, process, or procedure, it does not seem to capture the essence of everyday actions, which rather seem to rely on complex interactions between intentional and automatic processes. This has been clearly fleshed out by Exner (1879), who reported his introspection during a simple reaction-time experiment. Preparing for a task, so he

argues, involves some sort of self-automatization: one establishes a mental state that allows the later arriving stimulus to trigger the assigned reaction automatically. On the one hand, the entire action would be intentional, as it was the intentional preparation that allowed the stimulus to trigger the action. On the other hand, however, the action itself can be considered automatic, as it does not require some additional process to translate the stimulus into overt movement. Hence, goals and intentions allow us to prepare our cognitive system in such a way that further processing can be more or less entirely stimulus- or environmentally driven (Bargh, 1989, 1997)—a process that creates what Woodworth (1938) has called "prepared reflexes."

As pointed out earlier, this logic applies to many psychological phenomena, such as the Stroop effect, which involves automatic word-reading that nevertheless was enabled by the intention to utter color words in response to presented color words. A particularly convincing demonstration for the Simon effect stems from Valle-Inclán and Redondo (1998). The Simon effect consists in the observation that responding to non-spatial stimuli is easier and more efficient if the location of the stimulus corresponds to the location of the response (Simon & Rudell, 1967). This has been attributed to the automatic priming of responses by spatially corresponding stimuli, and there is indeed electrophysiological evidence that processing a lateralized or otherwise spatial stimulus activates cortical areas involved in planning movements with the corresponding hand (Eimer, 1995; Sommer, Leuthold, & Hermanutz, 1993). Valle-Inclán and Redondo (1998) were able to replicate this observation in a condition in which they presented the relevant stimulus-response mapping before the stimulus—a finding that would commonly be interpreted as demonstrating automaticity. And yet, the authors did not find automatic action activation in a condition where the stimulus-response mapping appeared after the stimulus. This means that implementing the stimulus-response mapping is a precondition of automaticity, suggesting that automatic action activation is actually a "prepared reflex."

How do people implement prepared reflexes? The implementation is commonly attributed to executive-control processes, but how the preparation works is still under investigation. At least three kinds of preparation processes seem to exist. First, preparing the cognitive system for goal-directed movements seems to include the establishment of stimulus–response links. Task-switching studies have revealed that implementing such links takes considerable time (Allport, Styles, & Hsieh, 1994; Monsell, 2003) and disabling them is difficult, as they are rather inert and affect subsequent processing (Allport et al., 1994; Hommel & Eglau, 2002). There is also evidence that maintaining stimulus–response links requires substantial cognitive effort (de Jong, Berendsen, & Cools, 1999), which in longer periods of task execution can induce goal forgetting (Altmann & Gray, 2002). Second, preparing for a task often involves the preactivation of possible actions. This is particularly likely if only a few action alternatives are relevant, while larger numbers of action alternatives are likely to prevent preactivation and to and use more cognitive response–selection strategies. And third, preparing for a task has been shown to include the attentional focusing on relevant stimuli (Bekkering & Neggers, 2002 (p. 269) ) and the

priming of task-relevant stimulus dimensions (Hommel, 2010; Memelink & Hommel, 2013). For instance, while preparing for a grasping action increases attention to the shape of visual stimuli, preparing for a pointing action attracts attention to location information (Fagioli, Hommel, & Schubotz, 2007).

These last two observations are likely to relate to another aspect of the interaction between offline preparation and online execution. There is considerable neuroscientific evidence that visually guided actions emerge from the interaction of two separate and dissociable stimulus–response routes. While earlier approaches have characterized these pathways in terms the particular stimulus information they provide (what vs. where), Milner and Goodale (1995) have emphasized the offline versus online character of these pathways. According to their reasoning, humans and other primates have a ventral offline channel for processing information that allows the identification of objects and other events and a dorsal online channel for providing real-time environmental information about location, intensity, and other rather low-level aspects of objects and events. Later approaches have criticized this approach for underestimating the interaction between the two channels (Glover, 2004) and for relating them to perception and action (rather than to action and sensorimotor processing), respectively (Hommel, Müsseler, Aschersleben, & Prinz, 2001a, 2001b). However, the basic idea that human action emerges from the interaction of preparatory offline processing and sensorimotor online processing has been widely embraced.

One problem with the original idea of two entirely independent channels was that the sensorimotor online channel was assumed to have no access to memory and higher-level processes, which raises the question of how it can be used to control flexible goal-directed actions. However, this problem can be tackled by assuming that offline preparation not only preactivates the relevant action systems into which sensorimotor processing would need to feed, but also selects the input provided to online sensorimotor processing by increasing the output gains, and thus the contribution of, features on task-relevant stimulus dimensions (Hommel, 2010). In other words, the sensorimotor online channel might indeed have some autonomy, but its contribution is tailored to the goal at hand by selecting its input and channeling its output to the relevant action systems.

# Action Selection and Prediction

The main purpose of ideomotor models of action control and of the theory of event coding (TEC) is to explain how people acquire the ability to select goal-directed actions. Figure 15.1 captures the main idea sketched earlier (see Hommel, 2009): random firing of motor cells produce overt movements, which are registered by the cognitive system and coded by sensory cells, which then become integrated with the corresponding motor cells through Hebbian learning. This integrated unit can then become internally activated through goal representations, that is, through representations that are coding for the intended action effects. Activating such representations will tend to activate sensory representations of similar events, and this activation primes the associated motor cells. To select an action, the agent simply needs to create a representation of the wanted action effect, which then leads to the selection of those motor patterns that have been produced such effects in the past.

Note that this approach is only concerned with setting up the cognitive system for producing an action, but not with testing whether this action has been carried out and whether it came out as expected. This testing aspect has been emphasized by comparator models of action control. Comparator models use cybernetic principles to compare intended output (actions) and the associated expected reafferent input (the sensory consequences of the action) against the actual reafferent input. Figure 15.2 sketches the basic principle. The representation of the desired state informs a perception-movement translation system to produce motor commands, which produce overt action. The perceived reafferent information is compared with the expected reafferent information to find out whether the intended action effect has actually been produced, that is, (p. 270) whether the action was as expected. A comparison between the actual outcome of the action and the wanted outcome serves to determine whether the action was successful in reaching the intended goal.

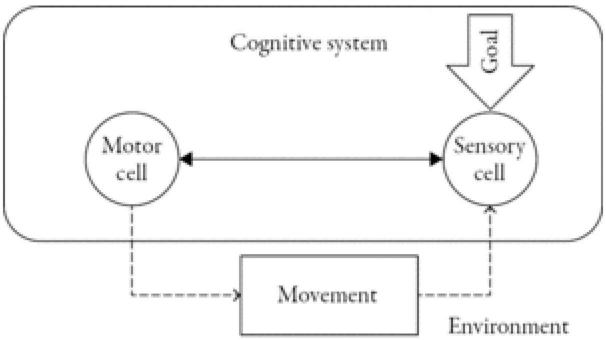


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*Figure 15.1* The ideomotor principle, simplified after James (1890).

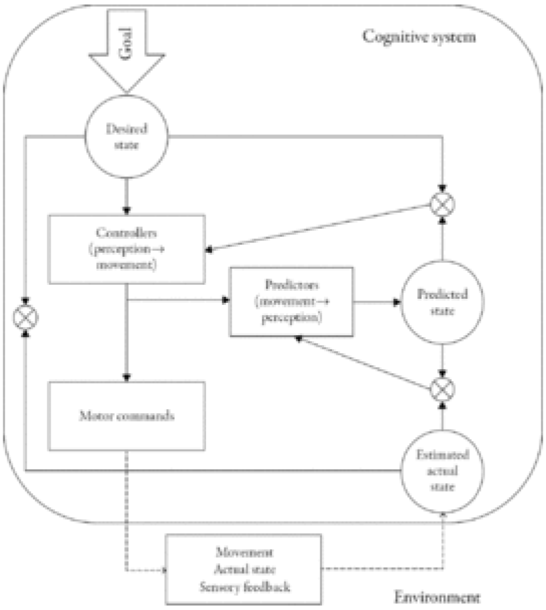


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*Figure 15.2* The basic structure of the comparator model, simplified after Frith, Blakemore, & Wolpert (2000).

It is easy to see that the ideomotor model and the comparator model of action control are complementary (see Chambon & Haggard, 2013; Hommel, 2015): the ideomotor model is rather articulated regarding the acquisition of action-effect associations and the selection of actions, but silent with respect to the evaluation of the outcome, while the comparator model is not overly specific with regard to the selection aspect, but very articulated regarding the outcome evaluation. One might consider the possibility that both models are simply using different language to refer to the same process, so that the process of selecting an action by anticipating an action effect might be the same that also specifies the outcome expectations, against which reafferent information can be evaluated. In other words, intending an action may simply consist in specifying the intended action effect, and this representation may be responsible for both selection and evaluation. However, there are reasons to assume that the scenario is more complex than that.

First, Elsner and Hommel (2004) investigated the conditions under which adults acquire novel action-effectcontingencies. Participants were presented with sounds that were contingent on pressing the left or right key before being presented with the same sounds as stimuli. As reported by Elsner and Hommel (2001), participants had more difficulties in pressing a key in response to a sound if that sound had previously been produced by the alternative key than if that sound had previously been produced by the same key. This suggests that the participants were spontaneously acquiring bidirectional action-effect associations in the first phase of the experiment. Interestingly, the size of this effect was systematically modulated by the contingency and the temporal contiguity between action and effect. The effect increased with the strength of (p. 271) correlation between action and effect and the frequency of the effect, and it was largest with zero delay between action and effect. Interestingly, Elsner and Hommel (2004) also assessed the perceived agency of the participants, that is, the degree to which participants perceive themselves to be the cause of the sounds. While agency judgments were also sensitive to contingency and temporal contiguity, the sizes of the action-effect learning effect and the degree of perceived agency were uncorrelated. If we assume that agency reflects the match

between the expected and the actual action effect, the representation of the expectation (as assessed by agency judgments) does not seem to be related to the representation that is responsible for a response selection (as assessed by the action–effect learning effect).

Second, Verschoor, Spapé, Biro, and Hommel (2013) investigated action-effect acquisition in 7- and 12-month-old infants (cf., Muentener & Bonawitz, Chapter 33 in this volume), and in adults. Participants were presented with sounds that were contingent on the horizontal direction of their saccades. In a later test phase, saccades were evoked by peripheral visual stimuli that appear together with a tone that was previously produced by left- or right-ward saccades. Saccade initiation was slower if that direction did not correspond with the direction associated with the tone, suggesting that saccades were selected based on representations of the resulting auditory effects. However, this effect was only observed in the 12-month-old infants and in the adults, but not in the youngest group. Consistent with earlier findings of Verschoor, Weidema, Biro, and Hommel (2010), this suggests that infants below one year of age have difficulties in selecting actions based on expected outcomes, presumably reflecting a not yet sufficiently developed frontal cortex. Verschoor et al. (2013) also measured pupil dilation, a measure of surprise. Participants exhibited more strongly dilated pupils if the actually carried out saccade went in another direction than the direction indicated by the tone—that is, participants were surprised by what they were doing currently because of the mismatch between the action-related expectation and the tone-induced expectation. Importantly, even the youngest group showed this effect, suggesting that representing expectations of action-contingent outcomes precedes, and thus does not require, the ability to use outcome expectations to select voluntary actions.

These findings suggest that action selection and action evaluation are separable processes that may develop at different paces and that seem to rely on different processes. As argued elsewhere (Hommel, 2015), this suggests the integration of ideomotor action selection and comparator-based action evaluation, as indicated in Figure 15.3.

# Agency and Ownership

Actions not only serve to reach particular goals, they also have a particular personal and social meaning. Accordingly, the ability to carry out goal-directed actions has often been associated with issues regarding agency and ownership of actions—issues of particular relevance for the juridical evaluation of deviant behavior. While it is debatable whether the experience of agency and ownership plays a decisive role in carrying out voluntary actions (an issue that I will discuss in the next section), recent (p. 272) research has looked into the factors determining such experiences.

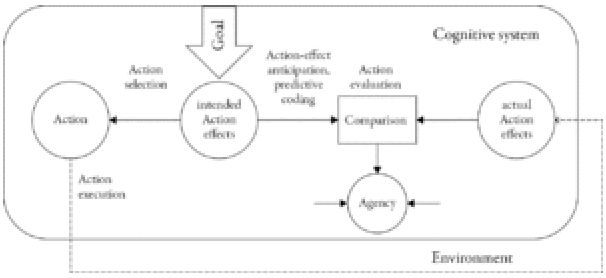


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*Figure 15.3* An integrated model combining ideomotor action selection with comparator-based action evaluation, redrawn after Hommel (2015).

Of particular interest for the experience of agency—that is, the impression that it is me who is carrying out (i.e., causally producing) a particular action—is the relationship between expected and actual action effects. More specifically, humans experience greater causal impact on events the stronger the temporal and spatial proximity between their actions and these events, and the more their actions and the events covary (for overviews, see LePelley, Griffiths & Beesley, Chapter 2 in this volume; Shanks & Dickinson, 1987; Wasserman, 1990). While the ideomotor approach does not really speak to the issue of agency, the comparator model provides a crucial comparison, namely, that between expected and actual reafferent stimulation (Frith et al., 2000). The assumption is that performing an action is accompanied by expectations regarding the sensory changes this action is assumed to evoke. These expectations are then matched with the actually produced sensory changes, and the better that match, the more pronounced the experience of agency might be (Chambon & Haggard, 2013).

This assumption is consistent with observations that expectation-inconsistent sensory action effects cause measurable surprise (Verschoor et al., 2013), a decreased sense of agency (Spengler, von Cramon, & Brass, 2009), and electrophysiological signs of internal conflict (a so-called feedback-related negativity, $N_{FB}$, which is commonly observed if agents are informed to have committed an error; Band et al., 2009). However, while the relationship between expected and actual outcomes is likely to be a major determinant of experienced agency, there are likely to be more sources for agency judgments, such as contextual plausibility, past experience, and the agent-specific typicality of the action. Hence, action control provides some input to agency judgments, but certainly not all, and sometimes perhaps not even the most important one (Synofzik, Vosgerau & Newen, 2008)—as Figure 15.3 indicates.

While agency refers to the attribution of action outcomes to oneself, perceived ownership refers to the attribution of effectors to oneself. Originally, interest in the mechanisms underlying body ownership was fueled by observations in patients, such as individuals suffering from the alien hand syndrome (Scepkowski & Cronin-Golomb, 2003). Some of these observations suggested that perceiving one’s own body is a non-trivial cognitive task that underlies all sorts of possible illusions and misinterpretations. Indeed, even healthy participants can have difficulties to tell whether it is their own hand or that of a confederate that is drawing a picture (Nielsen, 1963; van den Bos & Jeannerod, 2002). More recently, the so-called rubber-hand illusion has attracted a lot of attention. It shows that healthy individuals can be led to perceive a rubber hand lying in front of them as part of their own body if their own (invisible) hand and the rubber hand are stroked in

synchrony (Botvinick & Cohen, 1998). Synchronous stroking even induces some sort of primitive empathy: for instance, watching a synchronously stroked rubber hand about to being pricked by a pin activates the same pain areas in the brain that are activated when being approached by a pin oneself (Morrison, Lloyd, di Pellegrino, & Roberts, 2004). These observations suggest that multimodal synchronicity of perceptual input is one of the criteria that determine perceived body ownership.

Related investigations using virtual-reality manipulations have shown that active control or controllability is another, perhaps even more potent, criterion. If moving one's own hand leads to synchronous movements of a virtual hand on a screen or in a virtual-reality scenario, people perceive the virtual hand as part of their own body—the virtual-hand illusion (Sanchez-Vives, Spanlang, Frisoli, Bergamasco, & Slater, 2010). One possible implication of these kinds of effects is that humans might have an internal model of their body that mediates ownership perception (Tsakiris, 2010). Under suitable conditions, an artificial and/or novel candidate effector would thus be perceived as belonging to one's body, and to the degree that it is sufficiently similar to one of the effectors defined in this model. However, recent findings have shown that people can perceive ownership for virtual balloons that vary in size, and for virtual squares that vary in color, with people's own hand movements (Ma & Hommel, 2015). This suggests that controllability is more important, and can overrule similarity, which does not fit with the idea of a stable internal body model. It also suggests that agency, that is, the perception of contingencies between one's own actions and their effects, might be the crucial criterion for representing one's own body (Tsakiris, Schütz-Bosbach, & Gallagher, 2007).

# Consciousness and Action Control

Folk-psychological and philosophical traditions are based on the assumption that actions emerge from conscious decision-making and are controlled by conscious goal representations (Hommel, 2007). (p. 273) Indeed, early ideomotor theories were motivated by the question of how consciously represented action effects can recruit and drive consciously inaccessible motor processes (Baars, 1988; James, 1890) and information-processing approaches since Donders (1868) have often assumed that conscious representations shield the rather automatic perceptual processes from unwanted impact on action-related decision-making. Indeed, many introductory textbooks still contrast conscious decision-making with automatic processes, implying that unconscious decision-making cannot exist.

A highly influential milestone marking a transition in this thinking was the study of Libet, Wright, and Gleason (1982). In this study, participants were to carry out simple key-pressing actions at their own pace while their electrophysiological responses were continuously recorded. As expected, each key-pressing response was preceded by a readiness potential, a standard electrophysiological component that can be observed about one second or more before a voluntary action is performed. Participants were also asked to report when they would feel the urge to act. For that purpose, they saw a quickly rotating clock and they were reporting the position of the clock face at the point in time when they felt the urge at the end of each trial. Researchers were thus able to calculate the temporal relation between the electrophysiological indicator of the action (the readiness potential) and the conscious indicator (the perceived urge). While both indicators preceded the overt action, the theoretically significant observation was that the electrophysiological indicator preceded the conscious representation by several hundreds of milliseconds. This observation triggered numerous philosophical and psychological debates about the functional role, if any, of conscious goal representations (e.g., Klemm, 2010) and it has motivated Wegner (2003) to distinguish between the true cause of voluntary actions (which would produce the readiness potential) and its conscious representation—which he considers an only apparent cause.

Unfortunately, almost all of these discussions neglect basic aspects of action control, which actually render the findings of Libet and colleagues rather undiagnostic for assessing the role of conscious representations. As discussed under “Action and Habit,” actions are rarely controlled online. Rather, goals are translated into a task set, which then regulates information processing in a more or less automatic fashion (Bargh, 1989; Hommel, 2000). Indeed, given that the implementation of a task set is a rather time-consuming process taking several hundreds of milliseconds (Allport et al., 2004), reaction times in the order of a few hundred milliseconds, as in typical reaction time experiments, would not be possible if people would translate their goals into actions online in every trial. The same is likely to hold for tasks in the tradition of Libet et al. (1982), which require participants to carry out the same action hundreds of times in a row. The most

interesting time point for assessing conscious decision-making and goal representation in such a task would thus not be within a given trial but in the very beginning, when the participant translates the experimenter's instruction into a particular task set. In psychological experiments, negotiations between experimenters and participants are commonly verbal in nature, and goals are commonly explicitly defined. This renders it highly likely that goals are consciously represented, at least at the beginning of a given task. Whether and to what degree this extends to daily life is not yet understood.

At this point, the available evidence allows for four interpretations. First, it is possible that goals need to be consciously represented while agents implement a particular goal and action plan, but not necessarily after the implementation is completed. Second, it is possible that conscious representations often accompany but do not serve any purpose in action control proper. As pointed out by Wegner (2002), the idea that actions are controlled by conscious representations may thus be an illusion. Third, it is possible that conscious representations of action goals are unnecessary for immediate action control but serve the social communication about actions (Hommel, 2013; Masicampo & Baumeister, 2013). Finally, recent observations suggest that conscious representation may be systematically related to response conflict (Morsella, 2005), which might suggest a specific role for action monitoring.

# Action Monitoring

As pointed out earlier, the comparison between expected and actual action outcomes provides information about an action's success, that is, about whether the intended action effect has been realized. This can be considered a kind of action monitoring, as possible failures in achieving one's goals are signaled by discrepancies between expected and actual outcome. This allows for adjustments of actions in the future, so as to make them more likely to achieve one's goals. However, recent research has (p. 274) provided strong evidence for the existence of action monitoring at a less general level.

Most evidence comes from conflict tasks, such as the Stroop task or the Simon task, in which different aspects of stimuli indicate conflicting responses. These tasks indicate conflict within the trial by showing that stimulus-feature combinations that imply the same response (such as the word "red" written in red ink in a Stroop task, or a left-response cue appearing on the left side in a Simon task) allow for faster and more accurate responses than combinations that imply different responses (such as the word "green" written in red ink or a left-response cue appearing on the right side). Interestingly, however, trial-to-trial analyses of performance in conflict tasks have shown that conflict has less of an impact on performance after a conflict trial than after a non-conflict trial (Gratton, Coles, & Donchin, 1992). Even though various factors might contribute to this observation (Hommel, Proctor, & Vu, 2004; Spapé & Hommel, 2014),

this outcome pattern suggests that the experience of conflict leads to a readjustment of cognitive-control settings to reduce the impact of future conflict (Botvinick, 2007).

Neuroscientific evidence suggests that the presence of conflict in a given trial is communicated to brain areas involved in conflict monitoring (the anterior cingulate in particular; Botvinick, Nystrom, Fissell, Carter & Cohen, 1999), which then signal the demand for stronger top-down control to (frontal dorsolateral) systems involved in goal representation. As a consequence, the goal representation is strengthened and more top-down control is exerted, thus reducing the probability and strength of future conflict. One interesting question is how conflict is signaled to conflict monitoring systems. It is possible that conflict is picked up directly, but it may also be the case that it is conflict-induced reductions in mood that represent the relevant information (Botvinick, 2007). Indeed, receiving unexpected reward and positive-mood inductions reduce the probability of conflict-related adjustments (van Steenbergen, Band, & Hommel, 2009), suggesting that affective valence is the currency used to signal the presence of response conflict.

# Outlook

After decades of neglect (which is still obvious from almost all introductory textbooks in cognitive psychology), the question of how humans control goal-directed actions has received ample, and well-deserved attention in the last 20 years or so. The field is blooming and researchers have started to elaborate the cross-links between several areas, such as between consciousness and action control. And yet, quite some work needs to be done, and so I will conclude by discussing three challenges that would be particularly valuable to be tackled in the near future.

First, there is increasing insight into the embodiment of human cognition, that is, on the role of the body and of active interactions with our environment for the emergence of cognitive representations, including the construction of our self (Hommel, 2016; Wilson, 2002). Up to this point, however, the role of action is often referred to rather metaphorically and/or taken as a given, while systematic ontogenetic investigations or training studies actually demonstrating and tracking this emergence are lacking. Also lacking are mechanistic models that explain exactly how actions generate cognition and whether the role of action is restricted to the construction of cognitive models, or whether action remains important for the maintenance of cognitive representations.

Second, the cognitive sciences still tend to suffer from the stage approach to information processing and the idea that information processing mainly occurs in dedicated modules (e.g., Fodor, 1983; Sternberg, 2011). This approach has led to a rather drastic specialization of research on human cognition and action, and has prevented systematic communication between researchers working on particular modules, say, perception, attention, memory, thinking, language, and (non-verbal) action. Unfortunately, however, these concepts are taken from everyday language, which is not specialized for separating

underlying mechanisms. In fact, it is very likely that the mechanisms underlying these and other functions highly overlap. The neglect of this possibility has led to parallel developments and reinventions of various wheels, with modeling the control of complex, sequential action in the vocal and the non-vocal/non-verbal domain being just one of many examples. With respect to action, it is very likely that action control has a strong impact on almost all other cognitive processes, not the least because evolution, a major driving force in the phylogenetic development of our cognitive system, is selecting actions but not attention, memory, or other internal processes. And yet, there is very little attempt to create systematic places for action in research on these internal processes. Overcoming these kinds of splendid isolations requires the systematic development of more integrative and more ambitious approaches than those currently being discussed in the literature.

(p. 275) Third, psychology is an interface discipline connecting the humanities with science. With respect to action, this means that we are facing two very different approaches to human action: the humanities approach that emphasizes reasons and considerations leading to action, and the biological approach that emphasizes causes and mechanisms. The dividing line between these two different meta-theoretical approaches is even going through psychology, separating cognitive/neurocognitive psychology from social psychology. The recent years have seen very interesting attempts to overcome these kinds of divisions, for instance by developing mechanistic models of social phenomena and by considering socially relevant concepts in cognitive models. The systematic continuation and further development of these attempts provides interesting opportunities for psychology in bridging between different scientific languages and styles of thinking.

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