

5 Grounding Attention in Action Control: The Intentional Control of Selection

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My first poster presentation at a scientific meeting was no success. I offered a new theoretical framework on stimulus and response representation (the later theory of event coding; Hommel, Müsseler, Aschersleben, and Prinz 2001a) together with supportive data and hoped to attract the interest of all the big shots working on stimulus–response compatibility. But no one came. One year later I presented a much less inspired study but made one crucial move: I put the A-word in the title, with the effect that my poster was one of the most crowded, and long after the session was over I was still heavily engaged in discussions. This is just one of many examples demonstrating that cognitive scientists love attention as a topic. In contrast to sensory and motor processes, say, which rather smell like hardware and mechanics, the concept of attention seems to directly connect to what makes us human, as it somehow expresses our individual needs and wishes, preferences, and interests. The drawback of this attractiveness is that the concept is more often than not used as a wastebasket, a container that serves as a pseudo-explanation for the phenomena we still fail to understand—so that “attention” is explained by the workings of an “attentional system.”

One of the more successful strategies to tackle this problem is to focus on the function of attentional processes, that is, to ask what attention does rather than what it is. Indeed, the modern cognitive sciences have benefited greatly from this strategy, even though over the years we have seen rather dramatic changes in the way the functions of attention have been characterized. In the following, I will briefly discuss some of the more influential perspectives, which all have their benefits and their drawbacks. This discussion (for broader treatments, see Allport 1993; Neumann 1987; and Schneider 1995) will reveal that early approaches emphasized attentional function subserving higher order cognition and consciousness, whereas more recent approaches increasingly appreciate the importance of attentional processes for action (selection for action). In this chapter, I would like to push this trend one step further by arguing that attention not only subserves action-control processes but may actually have emerged to solve action-control problems in a cognitive system that relies on distributed representations and multiple, loosely connected processing streams.

The Functions of Attention

Most of the grand, influential attentional theories have considered attention as a mechanism that administers and organizes scarcity. In the 19th century authors were mainly impressed by the limits of consciousness, which was assumed to be restricted to the representation of only one thought or event at a time (e.g., James 1890). Given the emphasis on introspective methods, this limitation was rarely systematically investigated but rather taken for granted, and attention was thought to make the best of it. The main idea was that if consciousness can only contain one event, then attention better ensures that this event is of optimal use, which can be guaranteed by directing attention to relevant events (the endogenous aspect of attention) and having attention attracted by interesting events (the exogenous aspect of attention).

Even though modern cognitive approaches more or less did away with introspective methods, the assumed function of attention did not change much. In view of the increasing importance and availability of computers, researchers like Broadbent (1958) replaced consciousness with working memory as the central processing unit, which, however, was considered to be equally limited in processing capacity. Accordingly, attentional mechanisms were thought of as filters that discriminate between relevant and irrelevant information and effectively gate out the latter in order to prevent working memory from being overloaded. Again, the filters were thought to be endogenously controlled in principle, but this control could be overruled by overlearned or highly important stimuli. Emphasis on the coordinative and administrative aspects of attention was replaced by capacity theories (e.g., Kahneman 1973), which considered the flexible use of attentional resource policies and selection strategies in multiple task performance and everyday life. However, the main function of attention was again to prevent a central processing unit from being overloaded by gating out irrelevant information.

Recent attentional theories are more broadly informed by neuroscientific knowledge about the structure and processing characteristics of the primate brain and thus are necessarily more complex. Some theories are particularly interested in the spatial limitations of attention or, more precisely, in the apparent limitation of the brain to integrate information from only one point in space at one time (e.g., Treisman 1988; Wolfe 1994). Other approaches are less pessimistic with regard to strict spatial limitations, but they do assume that attended locations are processed at a higher spatial resolution (e.g., Bundesen, Habekost, and Kyllingsbaek 2005). Even though such theories are much more elaborated than their predecessors, they still share the basic logic that limited capacity must be administered and that attention has the job of doing that.

All of the approaches that I have discussed so far not only share the limited-capacity notion but also consider consciousness, or some philosophically less laden

equivalent (like working memory or the central processor), as the system that suffers from these limitations and has thus to be saved from overload. A few approaches have questioned this latter implication, however. Authors like Allport (1987) and Neumann (1987) have considered that it may not, or not so much, be conscious representation that constitutes the functionally important bottleneck but rather our action potentialities. As an example, visual attention may selectively focus on one of many apples on an apple tree not because one's conscious awareness would otherwise be overloaded but, rather, because one can actively pick only one apple at a time anyway. On the one hand, these approaches differ from the main tradition by considering action as more important than consciousness, culminating in the claim that selection is for action. On the other hand, however, the limited-capacity notion is not given up, as it is still scarcity (of action possibilities) that represents the main problem and attention that solves it.

In this chapter, I want to challenge not only the assumption that attention functions to prevent consciousness from overload (an aim that I share with selection-for-action approaches) but also that the management of scarcity has anything to do with the original biological function of attention. In particular, I will argue that attention is a direct derivative of mechanisms subserving the control of basic motor actions. I'm aware that this is an extreme statement that is likely to require modification in the light of new findings, but at the same time I believe that it can be inspiring and helpful by generating new insights and research questions. To motivate my suggestion, I will first set the theoretical stage by discussing the implications of the primate brain's preference to represent stimulus events and action plans in a distributed, feature-based fashion and to process information concurrently along multiple pathways. Then, I will discuss a number of empirical findings that support the general idea that action planning and action control can affect perception and attention, and I will develop a preliminary theoretical framework that grounds attention in action control.

Distributed Representations and Common Coding

Artificial intelligence, philosophical approaches, and many psychological models assume that the basic units of human cognition can be considered as symbols, so that cognitive processes can be reconstructed as symbol manipulation. Increasing evidence and deeper insights into the structure of the primate cortex suggest a different picture, however. Visual objects, for instance, are known to be coded in terms of their features, which are concurrently analyzed on various feature maps specialized in the processing of orientation, shape, color, motion, and more (DeYoe and Van Essen 1988). Even at higher representational levels, objects do not seem to be represented by single units but rather by composites of codes representing the parts and elements of objects (Tanaka 2003). This does not rule out the possibility that symbolic representations

exist in addition to that, but it does point to the fact that the human brain has a strong tendency to represent perceptual events in a distributed, feature-based fashion. This tendency is not restricted to perceptual coding. Separate neural networks code, among other things, the direction of an arm movement (Georgopoulos 1990), its force (Kalaska and Hyde 1985), and distance (Riehle and Requin 1989), suggesting that action plans are composites of codes of separately specified action features.

The distributed, feature-based representation of perceptual events and action plans is also reflected in numerous behavioral observations. For instance, searching for a single visual feature (a particular shape, say) in perceptually crowded scenes or arrays is much easier than searching for a feature conjunction (a particular shape in a particular color; Treisman and Gelade 1980), and if people are to report feature conjunctions under attentionally demanding conditions, they tend to fabricate illusionary conjunctions (Treisman and Schmidt 1982). With regard to action planning, different parameters of manual movements can be precued separately and through different stimuli, with the eventual reaction time decreasing as a function of the number of precues (e.g., Rosenbaum 1980; Lépine, Glencross, and Requin 1989). Even interactions between stimuli and actions provide evidence for feature-based representations: For instance, stimulus events prime responses, and action plans affect perceptual processes, if and to the degree that stimuli and responses share features, such as location (Hommel et al. 2001a; Kornblum, Hasbroucq, and Osman 1990).

Especially these latter observations—that stimulus representations and response representations can interact, and that these interactions depend on feature overlap—have important implications with regard to the question of how stimuli and responses are cognitively represented and how these representations are related. According to Hommel et al. (2001a), both perceived events (i.e., stimuli) and to-be-produced events (i.e., action plans) are represented by cognitive codes of their distal features and, thus, in a common format. These codes are composites of sensorimotor units, which relate perceived action effects to the motoric means employed to produce them (Elsner and Hommel 2001). According to this logic, seeing a red pen on one's desk, say, is the result of having directed one's eyes, and perhaps even one's head and body, toward the location of the pen, so that the visual information the pen provides is the action effect of these motor movements and will thus be integrated with them. Perceiving and acting is thus the same process, consisting of moving one's body in order to generate particular perceptions. If so, there is no qualitative difference between the representation of a stimulus event (which includes the action that has given rise to it) and the representation of an action plan (which includes the perceptual event the action aims at—the action goal, that is).

If perceptual events and action plans are represented in a common format, and if this format refers to bundles or bindings of perceptual features and motor parameters (Hommel 2004), one would expect that control processes operating on these cognitive

representations have characteristics that reflect this distributed, feature-based format. Indeed, there is increasing evidence that input and output control (i.e., attentional and intentional selection) operates on feature dimensions. For instance, when people search complex visual scenes for visually deviant targets (i.e., stimuli that pop out because of their unique color, shape, etc.), their performance will be better if they can anticipate the feature dimension on which an upcoming target will deviate (e.g., Müller, Heller, and Ziegler 1995). This suggests that people can strategically increase the weights or “gain” of a particular feature dimension in order to facilitate the coding of features falling on it (Found and Müller 1996). The same conclusion is suggested by observations from studies on task switching. In such studies, subjects often carry out responses to stimuli that are defined by one of multiple feature dimensions, such as to the color versus the meaning of colored color words (Allport, Styles, and Hsieh 1994) or to the horizontal versus vertical location of stimuli (e.g., Meiran 1996). Performance is much better if the task-relevant feature dimension is repeated than if it is alternated, suggesting that switching between different task sets takes time and effort. Importantly for our purposes, implementing a new task set is assumed to include directing attention to the target-defining stimulus dimension (Logan and Gordon 2001) and the response-defining action dimension (Meiran 2000). That is, executive control operates on feature dimensions, presumably by altering the weights that determine the degree to which features coded on these dimensions are considered by, or affect, cognitive processes.

Multiple Processing Pathways

There is increasing evidence that the human brain not only codes perceived and produced events in a distributed fashion but also concurrently processes different aspects of events along different neural pathways. One of the best known distinctions between parallel processing codes is that between the dorsal and the ventral pathway (Ungerleider and Mishkin 1982). Early approaches have characterized these two pathways in terms of “where” versus “what” processing. Whereas the dorsal pathway was considered to process spatial attributes of perceived events, the ventral pathway was thought to process identity-related attributes, such as shape and color. Later approaches, Milner and Goodale (1995) in particular, have suggested an alternative interpretation in terms of action-related (or pragmatic) processing versus perception-related processing. That is, the dorsal pathway was considered to directly feed into action control, without being accessible for conscious perception, whereas the ventral pathway was thought to mainly subserve conscious and unconscious perceptual processes. In view of increasing evidence that is not quite consistent with this particular subdivision, recent reformulations have suggested an interpretation in terms of online control of action—attributed to the dorsal pathway—versus action planning—

a presumably ventral activity (Glover 2004; Hommel, Müsseler, Aschersleben, and Prinz 2001b).

Interestingly, these neuroscientifically motivated considerations fit well with theoretical developments in the domain of action planning and control. Modern cognitive approaches were driven by the insight that human action is commonly goal driven and must, thus, be controlled by some kind of internal representation (Lashley 1951). Authors like Keele (1968) have pushed this possibility to an extreme and assumed that all muscle parameters and commands of a movement are stored and used to construct motor programs that prestructure all aspects of a movement in advance. Others, however, have pointed out that this possibility would put too high a demand on storage and render action planning very inflexible, as each slight change of a movement would require a separate program (Schmidt 1975). Theoretically more reasonable are hybrid approaches that assume that only some structural or invariant features of an action are stored and used for later programming, whereas more variable features are specified by online information (e.g., Schmidt 1975). Consistent with this consideration, studies have shown that transferring from one task to another is easier if the two tasks share invariant features, whereas changes in variant features do not affect performance much (see Heuer 1991).

Behavioral and neuroscientific approaches thus converge on the idea that action control is comprised of two processes: *action planning*, which consists of specifying the basic structure of an action, including its most relevant, invariant features, and which can be performed online as well as offline (i.e., some time before the action is executed), and online *action adjustment*, which consists of fine-tuning the action by specifying the remaining features and open parameters. A particularly elegant illustration of the interplay between action planning and action adjustment is provided by studies using the so-called double-step paradigm. For instance, in a study by Prablanc and Pélisson (1990), subjects were asked to move their right index finger from a home position to a light spot, and the spatial and temporal parameters of the movement were measured. In some trials, the target spot was moved a little further away from the subject while he or she was already moving. Importantly, the target was moved during an eye blink, so that subjects were unable to see the change. The most relevant outcome was that, first, the finger correctly reached the target even in change trials and that, second, this was achieved without any measurable hesitation of the moving hand. In a manner of speaking, the hand was smarter, better informed, and more adaptive than the mind. Thus, even though we can assume that goal-directed reaching movements are prepared and programmed in advance, a slight change in the location of the target does not require time-consuming modifications of the program or complete reprogramming. This means that the original program did not include specific information about the target location but left the specification of the details to online routines that adjusted the action on the fly.

Distributing the labor over different processing channels has obvious advantages: Storage and preplanning are minimized, and yet the resulting action is as precise as necessary. However, just as distributed representations create binding problems (Treisman 1996), distributed processing creates coordination problems. In one way or another, action-planning processes need to inform action-adjustment processes about which parameters to fill or specify and how to do so. For instance, Milner and Goodale (1995) claim that their dorsal action pathway does not have any memory capacity and does not interact with, nor is it informed by, ventrally mediated, conscious or unconscious decision making. This would imply that the channel that is dedicated to action control has no way to plan any action, has no way to retrieve or access any action plan, and cannot have any idea about currently relevant action goals. It is difficult to see how such a channel can do the job it is supposed to do: to select relevant sensory features and feed them into the action programs. Obviously, coherent, goal-directed action requires some kind of coordination between planning and adjustment processes, so that the latter can provide what the former leave open.

This chapter is devoted to this kind of coordination problem, and I will present a principled approach to how it might be solved. An important insight pointing to a possible solution is that concurrent processing streams need to be conditionalized by the current action goal. Action goals, so I will assume, govern the selection and planning of appropriate actions, and this planning process biases concurrent processing streams, such as the one in charge of action adjustments, toward information that is suitable to specify the action parameters that planning processes left open. A particularly interesting implication of this line of thought is that it requires action-related processes to affect perception and attention to perceptual input. Indeed, as the next section shows, there are numerous findings suggesting that action planning does affect perception and attention.

Action Control and Attention

An early suggestion that visual attention may be affected by action planning emerged from studies on the so-called meridian effect (Rizzolatti, Riggio, Dascola, and Umiltà 1987). This effect can be observed in studies that use attentional cues. Consider, for instance, a subject focusing on a central spot in a visual display, which further consists of four possible target locations marked by small frames, two at the left and two at the right of fixation. Now assume that, in each trial, one of the four locations is precued with high validity—that is, the subject knows in which of the four frames the target is likely to appear. If the target then actually appears in the precued frame, reaction times can be expected to be fast, suggesting that subjects “moved their attention” to the frame (Posner 1980). However, what if the target appears in an uncued frame? As Rizzolatti et al. (1987) observed, reaction times are not only slower in this

case but depend on the spatial relation between the cued frame and the eventual target location. If, for instance, one of the two inner frames was cued, performance was better if the target frame was located on the same side of the cue rather than on the opposite side. In other words, moving attention further into the same direction was less costly than changing the direction. According to the authors, this may suggest that attention is moved by programming (but not necessarily executing) an eye movement, which may require the sequential specification of a direction parameter and a distance parameter—in this order. If the direction stays the same (as when, say, the inner left frame is cued but the target appears in the outer left frame), only the distance parameter needs to be modified, which can be done faster than modifying the direction parameter or both parameters.

Further evidence for the general idea that the programming of eye movements is involved in directing visual attention to locations in space (see also Klein 1980) stems from Deubel and Schneider (1996; Schneider and Deubel 2002). Their subjects were to carry out saccades to visual targets on the left or right of a fixation point. Before moving their eyes, they were briefly flashed with a visual string of stimuli containing a to-be-discriminated target symbol. As it turned out, performance was good only if the location of the visual target coincided with the goal of the saccade, suggesting that programming the saccade involves moving attention to the goal location in advance of the saccade—which then facilitates the processing of stimuli appearing there. These observations are consistent with the premotor theory of attention but go beyond previous findings in directly demonstrating that saccade programming actually matters for spatial selection.

Interactions between the programming of eye movements and attentional selection support the idea that action planning affects attentional control, but they are too restricted to provide a basis for a comprehensive action-based theory of attention. First, even though linking overt and covert visual attention (i.e., attending by moving the physical versus the “mind’s” eye) has a long tradition in psychology (e.g., James 1890; Posner 1980), this may be due to the particularly strong and straightforward subcortical connections between retinal input processing and movements of the eye-balls. This raises the question of whether other than oculomotor action planning can affect attention. Second, the observed interactions between action and attention were restricted to spatial selection. Even though the spatial selection of relevant information plays an important role in perception and action, human attention subserves more functions than that—just think of object-based selection, action selection, and integration (Schneider 1995). Fortunately, however, there is increasing evidence of interactions between manual and verbal action planning and attentional functions other than spatial selection.

First evidence for the impact of manual action planning on visual processing was provided by Müsseler and colleagues. Müsseler and Hommel (1997), for instance, had

participants prepare a left- or right-hand key press and carry it out whenever they felt ready. To signal their readiness, they pressed a spatially neutral readiness key before performing the prepared action. Pressing the readiness key triggered the presentation of a masked visual arrowhead that pointed to the left or right. At the end of the trial, participants reported at leisure in which direction the arrowhead pointed, which, given the masking procedure, was difficult and attention demanding. The important observation was that the accuracy of the perceptual report was dependent on the relation between the prepared response and the direction of the arrowhead. If participants prepared and carried out a left-hand response, they had substantially more difficulty detecting a left-pointing than a right-pointing arrowhead, and the opposite was true for right-hand responses. In other words, planning a spatially defined manual action “blinded” the participants to perceptual events that shared features with the action.

Even though this finding seems counterintuitive, it fits with the idea that action planning consists in the binding of distributed feature codes that specify the action’s relevant characteristics (Stoet and Hommel 1999). Planning a left-hand action would thus require the binding of a <left> code with other relevant codes specifying, say, the speed, force, and extent of the key press. If we further assume that perceptual and action-related features are coded in the same format (Hommel et al. 2001a; Prinz 1990), “occupying” (Stoet and Hommel 1999) a given feature by binding it into an action plan should indeed impair the creation of another binding to represent a feature-overlapping perceptual event—such as a spatially compatible arrowhead. Other observations confirmed that this line of reasoning is not restricted to manual action plans or spatial relationships. For instance, planning a manual left or right action “blinds” participants to compatible left- or right-pointing arrowheads but not to the words “left” or “right,” whereas planning a vocal action (i.e., saying aloud “left” or “right”) impairs the perception of compatible words but not arrowheads (Hommel and Müsseler 2006).

Another demonstration of interactions between manual action planning and visual attention was provided by Craighero, Fadiga, Rizzolatti, and Umiltà (1999). They had participants manually grasp invisible objects that were tilted to the left or right. The type of grasp was planned ahead of time, but the execution had to await the presentation of a go signal. The orientation of this go signal did or did not match the orientation of the to-be-grasped object. It turned out that participants responded faster if the invisible target object and the go signal matched in orientation (and even if the go signal was responded to by foot), suggesting that planning a grasping action prepared the visual system for the processing of target-related features. Similarly, Bekkering and Neggiers (2002) had participants detect and grasp (vs. point to) visual targets defined by a conjunction of orientation and color features. The findings revealed that fewer orientation errors were committed when participants prepared for grasping as compared to pointing, whereas color errors were rare in all conditions. The authors argue

that planning a particular movement enhances the processing of features that specify the target of this movement. At first sight, these observations do not seem to fit with the inverse effect on feature overlap reported by Müsseler and Hommel (1997). However, while Müsseler and Hommel required participants to consciously perceive and report the perceptual events, participants in the Craighero et al. and Bekkering and Neggers studies were only using these events for triggering a more or less prepared response—a situation that is unlikely to require feature binding.

Let us summarize so far. The apparent distribution of labor between offline action-planning processes and online action adjustment introduces a control problem and raises the question of how action planning can make sure that adjustment processes select the appropriate sensory information and feed it into the relevant motor-control structures. We have seen a number of empirical phenomena suggesting that planning an action has a direct impact on attentional and perceptual processes, and we have also seen that this holds for oculomotor, manual, and vocal actions, and corresponding perceptual dimensions. In principle, it thus seems possible that action planning processes not only specify the task-relevant characteristics of a given action but also bias action-adjustment routines toward the relevant perceptual dimensions. And yet, there is one fly in the ointment: Whereas research on visual attention suggests that task goals lead to the priming and stronger weighting of appropriate perceptual *dimensions*, at least most of the available evidence for action-attention interactions points to stimulus-specific biases (e.g., the priming of one particular orientation in Craighero et al. 1999). The theoretical challenge thus consists in explaining why and how action planning can bias perceptual processing toward perceptual dimensions that provide information for specifying the open parameters of the action in question.

Intentional Control of Attention: A New Framework

The theoretical framework I want to propose here was motivated by an observation of Schubotz and von Cramon (2001, 2002). They had participants carry out an oddball task while lying in an fMRI scanner. Sequences of stimuli that followed a particular rule were presented (e.g., a repeated sequence of particular colors, locations, or shapes), and the participant was to report at leisure at the end of the trial whether one of the stimuli violated the rule. The important observation was that this perceptual monitoring task consistently activated the lateral premotor cortex, even in the absence of any motoric response. A meta-analysis of these and similar observations revealed systematic relationships between the task-relevant perceptual dimension and the particular area in the premotor cortex where the activation was located (Schubotz and von Cramon 2003). Three of these relations were particularly systematic: Location-relevant perceptual monitoring engaged premotor areas that are involved in the control of saccades and reaching movements, the monitoring of object-related features (such as

color or shape) activated premotor areas involved in the control of grasping movements, and the monitoring of rhythmic events engaged premotor areas responsible for controlling vocal actions and manual tapping. As the authors point out, these relationships suggest that action-related brain areas are directly involved in the control of attention and, in particular, in directing attention toward action-related perceptual dimensions.

These considerations were further developed by Fagioli, Hommel, and Schubotz (2007a). Preparing for a reaching movement, these authors reasoned, should sensitize the perceptual system for features of dimensions that are relevant for specifying the open parameters of reaching movements. Most likely, this criterion is met by location information. Preparing for a grasping movement, in turn, should sensitize the system for processing information about the final phase of the grasp, such as the size of the object signaling the hand's aperture. To test these hypotheses, the authors had participants reach toward or grasp an object in front of them. Before the action was executed, however, participants were presented with a sequence of stimuli following a particular rule, as in the setup of Schubotz and von Cramon (2001), and they were to detect possible oddballs. If an oddball occurred, the prepared reaching or grasping movement was carried out. As expected, the reaction times for these movements varied with the perceptual dimension on which the oddball was defined. Whereas reaching movements were initiated faster with location oddballs than with size oddballs, the opposite applied to grasping movements. To rule out that this effect was due to the oddball-induced priming of the movement, another experiment was carried out in which the detection of the oddball was signaled by a foot response. Again, preparing for a reaching movement facilitated the detection of location oddballs, and preparing for a grasping movement facilitated the detection of size oddballs.

These observations are consistent with the idea that action control encompasses the priming of perceptual dimensions, but one may argue that this connection is less direct than suggested here. For instance, it may be that a general executive control system not only selects appropriate responses but also implements a particular attentional set. Indeed, Logan and Gordon (2001) have suggested that executive control functions both bias attention toward task-relevant perceptual dimensions and specify the necessary stimulus–response rules without directly relating these two processes to each other or even deriving the attentional bias from action-control demands. In an attempt to provide more specific evidence for action-induced attentional biases, Fagioli, Ferlazzo, and Hommel (2007b) investigated whether the biases observed by Fagioli, Hommel, and Schubotz require active action planning. If activating an action plan is sufficient to induce the stronger weighting of related perceptual dimensions, they reasoned, such weighting should also be observed if the action plan is activated involuntarily. Participants again monitored sequences of stimuli and were to press a foot pedal as soon as they detected an oddball. They did not carry out any other action;

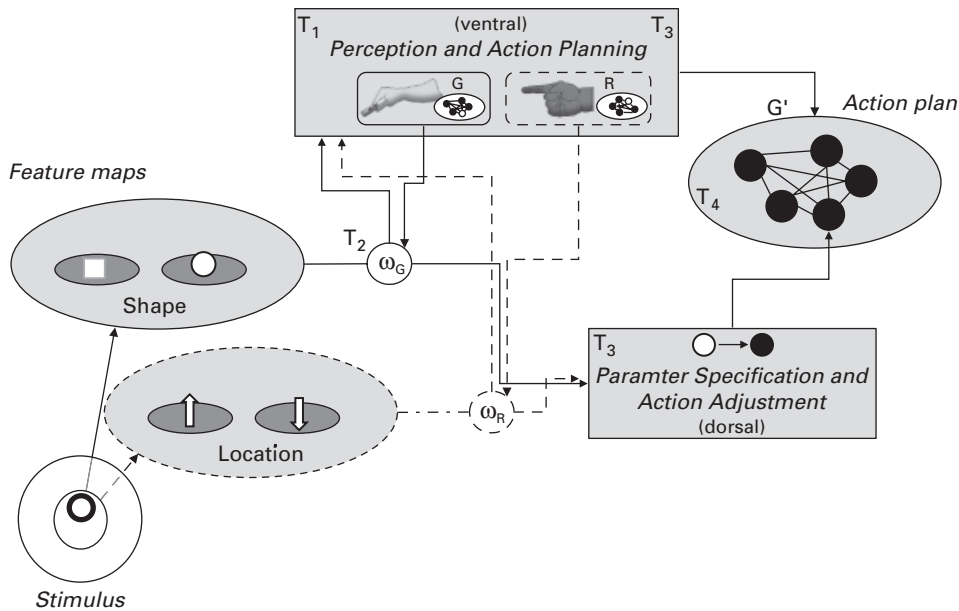


Figure 5.1
A process model of action-induced attention.

in particular, it should be noted that they made no reaching or grasping movement. However, prior to the stimulus sequences, short video clips that showed a person carrying out a reaching or grasping movement were presented. These videos were not relevant to the task and did not predict or inform about the stimulus sequences or the correct responses. Nevertheless, participants were faster at detecting location oddballs after seeing a reaching movement and size oddballs after seeing a grasping movement. Apparently, the videos activated reaching- and grasping-related action plans and this activation was sufficient to increase the weights of reaching- and grasping-related perceptual dimensions.

Taken together, these findings support the idea that the mere activation of an action plan—whether through top-down processes in the service of the current action goal or bottom-up, stimulus-induced processes—leads to an increase on the weights of those perceptual dimensions that allow for the specification of action parameters commonly left open by action planning. Figure 5.1 summarizes the theoretical implications of this consideration. As pointed out above, stimuli are assumed to be coded on feature maps, with each feature activating a code on the respective feature dimension (or multiple codes competing for coding the stimulus: Reynolds, Chelazzi, and Desimone 1999). In the example given, a circular object at some top location is coded

on a shape and a location map—a drastic simplification that is not meant to deny the existence of numerous other feature maps (such as color, motion, etc.), of multiple spatial maps (coding for, e.g., allocentric, egocentric, and retinal location), and of other sensory modalities.

This information is propagated to two different processing pathways, one subserving perception and action planning (similar but not identical to the ventral pathway of Milner and Goodale 1995, and comparable to the action-planning pathway of Glover 2004) and one subserving online action adjustments (comparable to Milner and Goodale's dorsal pathway and Glover's action-control pathway). Activating an action plan, such as for grasping or reaching (symbolized by the grasping and pointing hands in the figure), increases the weight (ω) of the output of particular feature maps, which increases the impact of information coded there on further information processes (i.e., perception and action planning on the one hand and action adjustment on the other). Following the theory of event coding (Hommel et al. 2001a), perception and action planning are not further differentiated, which acknowledges that these two functions highly interact and can be considered two sides of the same coin.

Perception and action planning creates action plans reflecting the current goal. Action plans consist of specified parameters (structural features of the planned action that are relevant for reaching the goal) and not-yet-specified parameters that are to be filled by online adjustment processes; in the figure, these parameters are symbolized by black and white circles, respectively. The open parameters are specified by continuously transmitting sensory information from feature maps to ongoing actions. This transmission is weighted by the output weight ω of the respective dimensions. Accordingly, given that planning a grasping action increases the weights for shape information, action-adjustment processes will mainly consider information provided by the shape map and use it to specify the remaining grasping parameters (such as hand aperture).

Note that the output weights have two functions in this model. On the one hand, they help to overcome the control problem posed by the existence of multiple concurrent processing streams by biasing online adjustment processes toward goal-relevant perceptual dimensions. On the other hand, they also bias perception and action planning toward these dimensions, a characteristic that is important in accounting for the findings of Fagioli et al. (2007a, 2007b). These findings suggest that planning an action leads to the faster conscious detection of stimuli varying on action-relevant perceptual dimensions, which implies that planning must have affected perceptual processes. Recent findings support the idea that action planning modulates conscious perception in systematic ways. Wykowska, Schubö, and Hommel (in press) presented participants with visual-search displays that contained to-be-detected pop-out targets—that is, stimuli that differed from all other stimuli of the display on one dimension. As in the studies of Fagioli and colleagues, participants prepared either a reaching or a grasping

action, and the target-defining dimensions were luminance (which was considered more important for reaching than for grasping) and size (which was considered more important for grasping than for reaching). If participants knew in advance on which perceptual dimensions a target would pop out, the prepared action biased attention systematically: Preparing a reach facilitated the detection of luminance-defined targets, and preparing a grasp facilitated the detection of size-defined targets. However, this effect was not observed when participants did not know the target-defining dimension in advance. Under this kind of uncertainty, participants are known to not prepare for a particular perceptual dimension but to rely on saliency signals—that is, they respond to any departure from homogeneity in the visual field without identifying the dimension on which it occurs (Bacon and Egeth 1994). Given the absence of action-induced biases in this type of processing, it makes sense to assume that these biases target the output of feature-map coding, but not the input or processes preceding or circumventing feature coding.

Theoretical Implications

The proposed framework has a number of interesting theoretical implications that break with the main line of reasoning underlying traditional attentional research. Most importantly, it denies that attentional functions emerged to distribute sparse cognitive resources to prevent the cognitive system from being overloaded. In contrast, it proposes that attentional functions originally evolved to deal with control problems arising from distributed representation and processing and from the share of labor between offline, anticipatory action planning and online action adjustment in particular. Once these functions were available, they could also be used for other purposes—that is, the weights of perceptual dimensions could be manipulated for other reasons than action adjustment and without actually preparing overt actions. It is this generalization that makes people good performers in visual-search experiments and related tasks. However, outside of the psychological laboratory, there are not too many occasions in which selective attention is needed for other purposes than action control—we commonly do not detect feature conjunctions in complex visual environments for the sake of detecting them but do so in the service of particular action goals. Considering this, selection-for-action approaches (Allport 1987; Neumann 1987) go in the right direction in emphasizing the theoretical importance of actions. However, the available evidence allows for an even more radical interpretation, according to which attentional functions not only consider action opportunities but may be a mere by-product of action control in a distributed processing system.

Given the systematic interactions between particular types of actions and particular perceptual dimensions, it is interesting to ask where this systematicity comes from. One possibility is phylogenetic development—that is, the discovery that some percep-

tual dimensions are more important for some actions than others may be an evolutionary achievement that became genetically coded over time. Alternatively, the selective use of perceptual dimensions may be an ontogenetic discovery. Consider, for instance, a learning process that is sensitive to the success of actions. In the beginning, actions may be carried out on the basis of any available information, with a noisy and random weighting of information provided by the available feature maps and very mixed results. The open parameters of an action—a grasp, say—would thus be randomly filled with all sorts of feature information. However, extensive experience will reveal that using size information renders grasping actions more successful than, say, using color information, and correlation learning would be sufficient to detect the relationship between different perceived sizes of the grasped object and the hand aperture in the final phase of a grasp. In other words, exploration in infancy and early childhood may allow for the discovery of optimal relationships between the consideration of particular perceptual dimensions on the one hand and particular action categories on the other.

Let us conclude by considering the implications of this suggested theoretical framework for the topic of this book, the issue of whether and when attentional processes are effortful or effortless. According to the suggested framework, attentional operations themselves are not effortful but are more or less automatically triggered by action-control processes, which again are coordinated by the current action goal (see Fagioli et al. 2007b). Hence, the selection, representation, and maintenance of an action goal would be a necessary precondition for attentional processes to operate, and these processes are commonly considered effortful. The most common task used to investigate goal implementation requires participants to switch between different, mutually incompatible action goals (e.g., Monsell 2003). Using this task has revealed two major findings that are important for our purposes. First, performance is strongly impaired in trials that require a goal switch, which has been taken to reflect time demands associated with establishing the new goal before going on with the task details (e.g., Rogers and Monsell 1995; Meiran 1996). Second, even task repetitions have been found to show performance decreases over time, suggesting that goal maintenance requires some effort (e.g., Altmann 2002). Even though such observations seem to make a strong case for effortful goal operations, there are reasons not to jump to conclusions. Waszak, Hommel, and Allport (2003) provided evidence that task goals can become associated with particular stimuli, so that these stimuli can act as exogenous retrieval cues for these goals. Along the same lines, Logan and Bundesen (2003) observed that most of the difficulty in switching between different goals is due to a shift in the task cues that signal the different goals—again suggesting that goal selection can become stimulus driven under appropriate circumstances. Indeed, Bargh and Gollwitzer (1994; Bargh, Gollwitzer, Chai, Barndollar, and Troetschel 2001) have claimed that everyday behavior is often driven by external cues, which would allow

for effortless goal selection. Similarly, even if goal maintenance turned out to require effort in artificial laboratory tasks, the goals we maintain in everyday life are commonly consistent with, and thus supported by, long-term motives and overarching goals as well as by environmental cues. Indeed, in situations in which the available stimuli are specifically associated with different tasks, switching between tasks and goals was not found to be effortful or performance costly (Jersild 1927). Taken altogether, it may thus be possible that the frequent use of artificial tasks that are not deeply anchored in the participant's motivational structure and not supported by environmental cues has led to a rather drastic overestimation of the cognitive effort needed to deal with everyday life.

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References

- Allport, A. 1987. Selection for action: Some behavioral and neurophysiological considerations of attention and action. In *Perspectives on perception and action*, ed. H. Heuer and A. F. Sanders. Hillsdale, NJ: Erlbaum, 395–419.
- Allport, D. A. 1993. Attention and control: Have we been asking the wrong questions? A critical review of twenty-five years. In *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience*, ed. D. E. Meyer and S. Kornblum. Cambridge: MIT Press, 183–218.
- Allport, A., E. A. Styles, and S. Hsieh. 1994. Shifting intentional set: Exploring the dynamic control of tasks. In *Attention and performance XV: Conscious and nonconscious information processing*, ed. C. Umiltà and M. Moscovitch. Cambridge: MIT Press, 421–452.
- Altmann, E. M. 2002. Functional decay of memory for tasks. *Psychol. Res.* 66:287–297.
- Bacon, W. F., and H. E. Egeth. 1994. Overriding stimulus-driven attentional capture. *Percept. Psychophys.* 55:485–496.
- Bargh, J. A., and P. M. Gollwitzer. 1994. Environmental control over goal-directed action. *Nebr. Symp. Motiv.* 41:71–124.
- Bargh, J. A., P. M. Gollwitzer, A. L. Chai, K. Barndollar, and R. Troetschel. 2001. Automated will: Nonconscious activation and pursuit of behavioral goals. *J. Pers. Soc. Psychol.* 81:1014–1027.
- Bekkering, H., and S. F. W. Neggers. 2002. Visual search is modulated by action intentions. *Psychol. Sci.* 13:370–374.
- Broadbent, D. E. 1958. *Perception and communication*. London: Pergamon.

- Bundesen, C., T. Habekost, and S. Kyllingsbaek. 2005. A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychol. Rev.* 112:291–328.
- Craighero, L., L. Fadiga, G. Rizzolatti, and C. A. Umiltà. 1999. Action for perception: A motor-visual attentional effect. *J. Exp. Psychol. Hum. Percept. Perform.* 25:1673–1692.
- Deubel, H., and W. X. Schneider. 1996. Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Res.* 36:1827–1837.
- DeYoe, E. A., and D. C. Van Essen. 1988. Concurrent processing streams in monkey visual cortex. *Trends Neurosci.* 11:219–226.
- Elsner, B., and B. Hommel. 2001. Effect anticipation and action control. *J. Exp. Psychol. Hum. Percept. Perform.* 27:229–240.
- Fagioli, S., F. Ferlazzo, and B. Hommel. 2007b. Controlling attention through action: Observing actions primes action-related stimulus dimensions. *Neuropsychologia* 45:3351–3355.
- Fagioli, S., B. Hommel, and R. I. Schubotz. 2007a. Intentional control of attention: Action planning primes action related stimulus dimensions. *Psychol. Res.* 71:22–29.
- Found, A., and H. J. Müller. 1996. Searching for unknown feature targets on more than one dimension: Investigating a “dimension weighting” account. *Percept. Psychophys.* 58:88–101.
- Georgopoulos, A. P. 1990. Neurophysiology of reaching. In *Attention and performance XIII: Motor representation and control*, ed. M. Jeannerod. Hillsdale, NJ: Erlbaum, 227–263.
- Glover, S. 2004. Separate visual representations in the planning and control of action. *Behav. Brain Sci.* 27:3–24.
- Heuer, H. 1991. Invariant relative timing in motor-program theory. In *The development of timing control and temporal organization in coordinated action*, ed. J. Fagard and P. H. Wolff. Amsterdam: North-Holland, 37–68.
- Hommel, B. 2004. Event files: Feature binding in and across perception and action. *Trends Cogn. Sci.* 8:494–500.
- Hommel, B., and J. Müsseler. 2006. Action-feature integration blinds to feature-overlapping perceptual events: Evidence from manual and vocal actions. *Q. J. Exp. Psychol.* 59:509–523.
- Hommel, B., J. Müsseler, G. Aschersleben, and W. Prinz. 2001a. The theory of event coding (TEC): A framework for perception and action planning. *Behav. Brain Sci.* 24:849–878.
- Hommel, B., J. Müsseler, G. Aschersleben, and W. Prinz. 2001b. Codes and their vicissitudes. *Behav. Brain Sci.* 24:910–927.
- James, W. 1890. *The principles of psychology*. New York: Dover Publications.
- Jersild, A. T. 1927. Mental set and shift. *Archive of Psychology*, whole no. 89.
- Kahneman, D. 1973. *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

- Kalaska, J. F., and M. L. Hyde. 1985. Area 4 and area 5: Differences between the load direction-dependent discharge variability of cells during active postural fixation. *Exp. Brain Res.* 59:197–202.
- Keele, S. W. 1968. Movement control in skilled motor performance. *Psychol. Bull.* 70:387–403.
- Klein, R. 1980. Does oculomotor readiness mediate cognitive control of visual attention? In *Attention and performance VIII*, ed. R. S. Nickerson. Hillsdale, NJ: Erlbaum, 259–276.
- Kornblum, S., T. Hasbroucq, and A. Osman. 1990. Dimensional overlap: Cognitive basis of stimulus–response compatibility—A model and taxonomy. *Psychol. Rev.* 97:253–270.
- Lashley, K. S. 1951. The problem of serial order in behavior. In *Cerebral mechanisms in behavior*, ed. L. A. Jeffress. New York: Wiley, 112–146.
- Lépine, D., D. Glencross, and J. Requin. 1989. Some experimental evidence for and against a parametric conception of movement programming. *J. Exp. Psychol. Hum. Percept. Perform.* 15:347–362.
- Logan, G. D., and C. Bundesen. 2003. Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *J. Exp. Psychol. Hum. Percept. Perform.* 29:575–599.
- Logan, G. D., and R. D. Gordon. 2001. Executive control of visual attention in dual-task situations. *Psychol. Rev.* 108:393–434.
- Meiran, N. 1996. Reconfiguration of processing mode prior to task performance. *J. Exp. Psychol. Learn. Mem. Cogn.* 22:1423–1442.
- Meiran, N. 2000. Modeling cognitive control in task-switching. *Psychol. Res.* 63:234–249.
- Milner, A. D., and M. A. Goodale. 1995. *The visual brain in action*. Oxford: Oxford University Press.
- Monsell, S. 2003. Task switching. *Trends Cogn. Sci.* 7:134–140.
- Müller, H. J., D. Heller, and J. Ziegler. 1995. Visual search for singleton feature targets within and across feature dimensions. *Percept. Psychophys.* 57:1–17.
- Müsseler, J., and B. Hommel. 1997. Blindness to response-compatible stimuli. *J. Exp. Psychol. Hum. Percept. Perform.* 23:861–872.
- Neumann, O. 1987. Beyond capacity: A functional view of attention. In *Perspectives on perception and action*, ed. H. Heuer and A. F. Sanders. Hillsdale, NJ: Erlbaum, 361–394.
- Posner, M. I. 1980. Orienting of attention. *Q. J. Exp. Psychol.* 32:3–25.
- Prablanc, C., and D. Pélisson. 1990. Gaze saccade orienting and hand pointing are locked to their goal by quick internal loops. In *Attention and performance XIII: Motor representation and control*, ed. M. Jeannerod. Hillsdale, NJ: Erlbaum, 653–676.
- Prinz, W. 1990. A common coding approach to perception and action. In *Relationships between perception and action: Current approaches*, ed. O. Neumann and W. Prinz. Berlin: Springer, 167–201.

- Reynolds, J. H., L. Chelazzi, and R. Desimone. 1999. Competitive mechanisms subserve attention in macaque areas V2 and V4. *J. Neurosci.* 19:1736–1753.
- Riehle, A., and J. Requin. 1989. Monkey primary motor and premotor cortex: Single-cell activity related to prior information about direction and extent of an intended movement. *J. Neurophysiol.* 61:534–549.
- Rizzolatti, G., L. Riggio, I. Dascola, and C. Umiltà. 1987. Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia* 25:31–40.
- Rogers, R. D., and S. Monsell. 1995. Costs of a predictable switch between simple cognitive tasks. *J. Exp. Psychol. Gen.* 124:207–231.
- Rosenbaum, D. A. 1980. Human movement initiation: Specification of arm, direction and extent. *J. Exp. Psychol. Gen.* 109:444–474.
- Schmidt, R. A. 1975. A schema theory of discrete motor skill learning. *Psychol. Rev.* 82:225–260.
- Schneider, W. X. 1995. VAM: A neuro-cognitive model for visual attention control of segmentation, object recognition, and space-based motor action. *Vis. Cogn.* 2:331–376.
- Schneider, W. X., and H. Deubel. 2002. Selection-for-perception and selection-for-spatial-motor-action are coupled by visual attention: A review of recent findings and new evidence from stimulus-driven saccade control. In *Attention and performance XIX: Common mechanisms in perception and action*, ed. W. Prinz and B. Hommel. Oxford: Oxford University Press, 609–627.
- Schubotz, R. I., and D. Y. von Cramon. 2001. Functional organization of the lateral premotor cortex: fMRI reveals different regions activated by anticipation of object properties, location and speed. *Brain Res. Cogn. Brain Res.* 11:97–112.
- Schubotz, R. I., and D. Y. von Cramon. 2002. Predicting perceptual events activates corresponding motor schemes in lateral premotor cortex: An fMRI study. *Neuroimage* 15:787–796.
- Schubotz, R. I., and D. Y. von Cramon. 2003. Functional-anatomical concepts of human premotor cortex: Evidence from fMRI and PET studies. *Neuroimage* 20:S120–S131.
- Stoet, G., and B. Hommel. 1999. Action planning and the temporal binding of response codes. *J. Exp. Psychol. Hum. Percept. Perform.* 25:1625–1640.
- Tanaka, K. 2003. Columns for complex visual object features in the inferotemporal cortex: Clustering of cells with similar but slightly different stimulus selectivities. *Cereb. Cortex* 13:90–99.
- Treisman, A. 1988. Features and objects: The Fourteenth Bartlett Memorial Lecture. *Q. J. Exp. Psychol.* 40A:201–237.
- Treisman, A. 1996. The binding problem. *Curr. Opin. Neurobiol.* 6:171–178.
- Treisman, A., and G. Gelade. 1980. A feature-integration theory of attention. *Cognit. Psychol.* 12:97–136.

Treisman, A., and H. Schmidt. 1982. Illusory conjunctions in the perception of objects. *Cognit. Psychol.* 14:107–141.

Ungerleider, L. G., and M. Mishkin. 1982. Two cortical visual systems. In *Analysis of visual behaviour*, ed. D. J. Ingle, M. A. Goodale, and R. J. W. Mansfield. Cambridge, MA: MIT Press, 549–586.

Waszak, F., B. Hommel, and A. Allport. 2003. Task-switching and long-term priming: Role of episodic stimulus-task bindings in task-shift costs. *Cognit. Psychol.* 46:361–413.

Wolfe, J. M. 1994. Guided Search 2.0: A revised model of visual search. *Psychon. Bull. Rev.* 1:202–238.

Wykowska, A., A. Schubö, and B. Hommel. in press. How you move is what you see: Action planning biases selection in visual search. *J. Exp. Psychol. Hum. Percept. Perform.*