Action as stimulus control

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SUMMARY

According to conventional psychological wisdom the relationship between perception and action is uni-directional: Perceiving informs an individual about the environment and acting results as a more or less adequate response to the perceived situation. Following Dewey (1896) and others we argue that this is only half of the story. In fact, humans commonly act not in order to respond to, but to *produce* stimuli. Action is defined as goal-directed movement and goals as intended movement- or action-contingent stimulus events. Accordingly, selecting an action must be in terms of the expected action-contingent stimulation the actor aims at. This again implies that action representations must comprise both motor-related codes and codes of sensory action effects. We will present a two-stage model of how these codes are acquired, integrated, and used for intentional action. We also report on a number of studies from our lab concerning the acquisition of acoustic action effects that provide solid ground for our approach.

BEHAVIOR AS STIMULATED RESPONSE: THE BEHAVIORISTIC LEGACY TO COGNITIVE PSYCHOLOGY

The transition from behaviorism to the information processing approach during the cognitive revolution in psychology has involved various changes in research methodologies and theoretical perspectives. Behavior is no longer analyzed purely in terms of the physical characteristics of external stimuli and overt, observable responses, but internal perceptual processes and cognitive operations of all sorts have become scientifically acceptable, major topics in experimental psychology. One thing, however, has remained entirely unchanged, namely the idea that human behavior is best described in terms of responses to environmental stimuli. Accordingly, virtually any up-to-date introductory psychological textbook represents the interaction of the human cognitive system with environmental information in terms of flow charts as sketched in Figure 1. In these flow charts, the stimulus always comes first and initiates a number of coding and recoding operations that eventually lead to a covert or overt response.

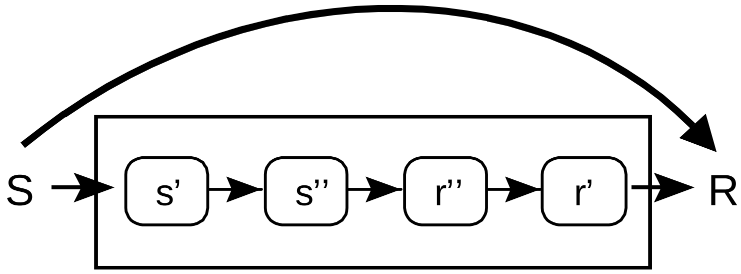

Figure 1: Sketch of the standard model of human information processing. A given stimulus S is assumed to be registered by sensory stages (s'), transmitted to higher-order perceptual stages (s''), translated into higher-order action-decision centers (r''), downloaded to motor stages (r'), and then output as response R.

Although such a view provides an apt characterization of the typical situation in psychological experiments, it stands in striking contrast to everyday human behavior. Actually, humans rarely wait for stimuli to tell them what to do. They rather actively seek environmental situations to support their goal-directed actions, which they perform to change these situations and create new ones that fulfill their wants and needs. This implies that beginning a psychological analysis with the stimulus, a striking commonality of behavioristic and cognitive approaches, may not lead to a representative picture of what humans do and of how they do it.

In the remainder of this article, we propose an alternative approach to human information processing that reverses the roles of stimulus and response by taking actions as the preconditions and determinants of perception. In doing so, we follow Dewey's (1896) early criticism of the reflex-arc conception that at his time began to dominate psychological thinking. After sketching Dewey's arguments, we describe a model of voluntary action that takes his arguments into account, and present then findings from our lab that provide ample support for the basic assumptions of the model.

DEWEY AND THE MISSING PART OF THE REFLEX ARC

American behaviorism arose at the turn of the last century as a consequence of both the growing dissatisfaction with introspectively driven armchair approaches to psychological problems and the promising scientific breakthroughs in the physiology of these days. Given that, it comes with little surprise that the concept of the reflex arc represents the backbone of behavioristic thinking. However, as early as in 1896 John Dewey, a leading figure of the pragmatist movement from which behaviorism grew, published a word of caution that this S-R perspective may be too restricted. One of the examples he used to clarify his point was taken from auditory perception. Assume a perceiver is confronted with a loud, unexpected sound that catches her attention and makes her shrink back in an attempt to escape possible danger. At first sight, this seems to be a perfect case for an account in S-R terms, with the stimulus more or less directly triggering the response, possibly mediated by emotions of fear or a swift rational calculation of risk. At second sight, however, such an analysis neglects at least two psychologically important facts, as Dewey points out in detail.

First, perceiving a stimulus is more than passively registering physical energy and transforming it into some perceptual experience. Hearing is an active, temporally extended process of orienting the ears and head and sometimes even the whole body towards the source of information, involving continuous adjustments of receptors and body posture to optimize the acquisition of relevant information. That is, hearing is a goal-directed action or, in the words of Dewey, an active sensori-motor coordination that actually *produces* the stimulus. Obviously, the complexity and the dynamics of this process is hardly captured by terms like "stimulus perception" or the more fashionable "processing of stimulus information".

Second, along the same lines, the withdrawal of a body part and the escape from a sound are not mere motor responses but goal-directed actions involving complex sensori-motor coordination themselves. Moreover, the stimulus does not just trigger an associated response that then runs off independently, but it directs and steers the response in a goal-directed fashion. After all, escaping from a sound is an action that aims at reducing the sound's impact on the escaping person, so that the action is continuously defined by the values of the impacting sound features, such as decreasing loudness.

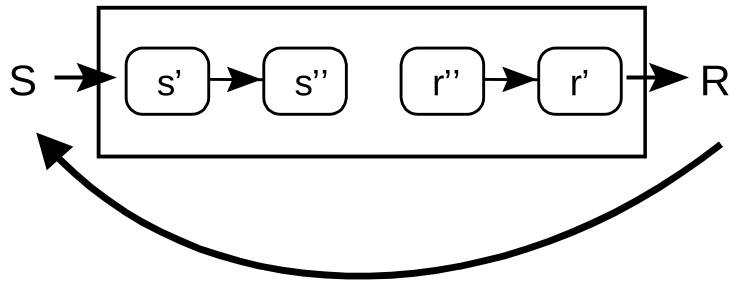

Figure 2: The missing part in the reflex arc conception. Most human activities are not triggered by a stimulus S but are performed to intentionally produce particular stimuli. That is, "responses" R are planned and executed to bring about the perception of goal stimuli S.

From this perspective, escaping from a sound is only insufficiently characterized as auditory perception followed by a motor response. Instead, as Dewey (1896) emphasizes, both perceiving and responding are integrated activities each comprising perceptual and action components. In fact, the functions are highly related: Perceiving a sound involves action directed toward optimizing the intake of auditory information and escaping from it involves action directed towards minimizing the intake of auditory information. That is, perceiving a stimulus and responding to it is not so much an example of stimulus-triggered behavior but of an ordered sequence of related, goal-directed sensori-motor coordinations.

If we follow this line of thought, we must confess that the conception of the reflex arc still dominating psychology tells only half of the story. True, part of human information processing might be reasonably represented by assuming a flow of information from stimulus input to motor output as depicted in Figure 1. However, it is also true that a considerable part of human behavior consists of goal-directed action that is not triggered by stimuli but aims at producing them, just as sketched in Figure 2.

BEHAVIOR AS STIMULUS CONTROL: A TWO-STAGE MODEL OF VOLUNTARY ACTION

We have argued that both human perception and action can be understood as operations of intentional stimulus control (see contributions to Jordan, 1998, for elaborations of this theme). That is, a reasonable model of human behavior needs to account for how perceptual and action-related processes interact in order to produce perceptual experiences and to bring about intended action goals. Hommel and colleagues have proposed a theoretical framework from which such a model might be developed, the Action Concept Model (ACM; Elsner & Hommel, 1999a; Hommel, 1996, 1997, 1998). This model goes back to ideas of Lotze (1852) and Harleß (1861), and it aims at explaining how voluntary action emerges in newborns and, under some circumstances, in adults meeting new environmental conditions and action possibilities.

Figure 3: Phases of Stage 1 (upper row) and Stage 2 (lower row) of the acquisition of voluntary action according to the Action Concept Model.

Figure 3 shows the basic logic underlying the model. As an example, take a newborn child in the process of discovering its environment. In the very beginning, voluntary action is impossible for obvious reasons: Performing a voluntary action means to carry out particular movements in order to produce a particular goal event. Yet, without knowing which movement produces which effect, hence without knowing about movement consequences, the movement cannot be goal directed. Therefore, the first step in the development of voluntary action needs to be the acquisition of knowledge about movement-contingent events. How this might work according to the ACM is shown in the upper row of Figure 3. First, some arbitrary movement pattern is set up as a consequence of reflexes, emotional states, motor noise, or whatever (1A). Activating this pattern will produce external movement-contingent events that are, or at least can be, perceived and registered by the performing person (1B). Due to the temporal overlap of motor activity and event perception, the codes representing and controlling the motor pattern and the event perception will be automatically associated, thus forming an integrated perception-action complex or, as we call it, an *action concept* (1C).

Once an action concept has been formed, the links between effect and motor codes can be used either way. That is, if an actor aims at producing some effect e_2, say, she only needs to activate the code of the intended action effect (2A), thereby activating the action concept this code belongs to—including the concept's motor part (2B). As a consequence, the corresponding action will be performed and, hopefully, the intended action effect will be produced (2C).

Although the case of a newborn child provides a particularly good example for describing how our model works, the model is not limited to the first months of age. In fact, adults often find themselves in situations where their knowledge is comparable to that of an unexperienced infant, such as when learning to drive a car, figuring out the function of a technical instrument, or beginning to work with a new text processor. What these situations have in common is that the people facing them do not yet know enough about the relations and contingencies between particular movements and their effects to act in a goal-directed fashion. Accordingly, they will explore the situation by testing new actions, or by employing actions from their repertoire that proved useful in similar situations, so to acquire the new relations between actions and their effects. Although, depending on the individual strategy, this may sometimes look more systematic than the exploratory behavior of infants, the basic problem is very much the same, suggesting that the same learning principles apply. If so, we can test our model by confronting adult subjects with situations that provide new, artificial action effects and see whether these effects are acquired as assumed in the model and whether they lead to the formation of action concepts. And this is what we did. In the following, we will provide an overview of findings from our lab that are relevant for the issue of how and under what conditions action effects are learned, and whether actions are really planned and performed the way the ACM hypothesizes.

ACQUISITON OF AUDITORY ACTION EFFECTS

In all our experiments adults worked through two phases. The first phase was an *acquisition phase*, in which actions were paired with task-irrelevant, action-contingent tones. For example, subjects were presented with the letter O or X, which signaled a left- and right-hand keypress, respectively. Importantly, each action was paired with an artificial action effect, such as a low- vs. high-pitched tone. That is, as soon as a key was depressed a tone was presented, say, a low-pitched tone with the left key and a high-pitched tone with the right key (see Figure 4). According to the ACM the contingency between keypress and tone should lead to an integration of the code representing the tone pitch (an action effect) and the motor

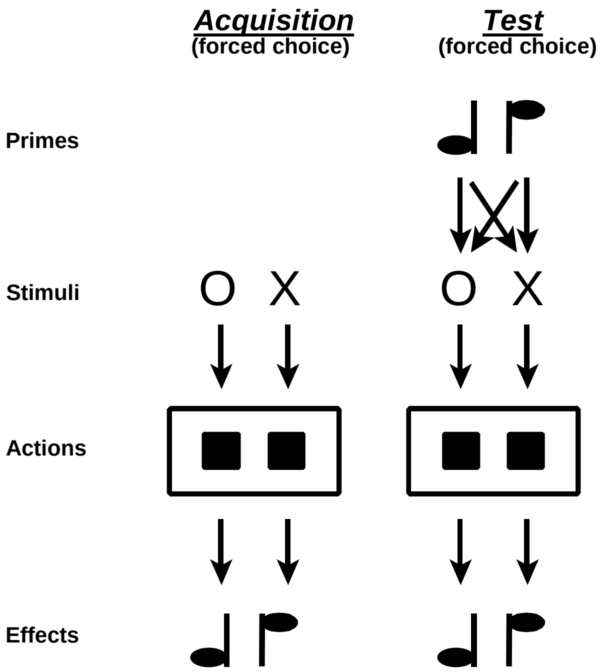

Figure 4. Basic design of Hommel (1996) and Elsner & Hommel (1998).

pattern responsible for the keypressing action. If so, activating the code of a tone should activate or prime the corresponding action—in our example, the low tone the left-hand keypress and the high tone the right-hand keypress. To test that, we introduced a second, *test phase*. It consisted basically of the same task, but now the letters were accompanied or preceded by randomly chosen low or high tones (see Figure 4). This manipulation introduced *compatible* conditions, where the tone was associated with the response that was also signaled by the letter (e.g., O and low tone), and *incompatible* conditions, where tone and letter were associated with different responses (e.g., O and high tone). From a ACM point of view, we expected compatible conditions to allow for better performance than incompatible conditions.

Indeed, Hommel (1996) observed faster reaction times with response-compatible than incompatible tone primes in a number of experiments using different stimuli and responses. This indicates that novel action-contingent events are associated with the action they accompany, so that perceiving the event again tends to reactivate the corresponding action. This is the more surprising as the action-effect tones were completely irrelevant to the task at hand and, thus, could be ignored altogether.

In a further series of experiments, Elsner and Hommel (1998) investigated whether and how effect integration varies over time. As Hommel's (1996) subjects were performing in only one session, we were unable to exclude that the tone-priming effect was just a transient effect of curiosity or disturbance. For instance, when presented with the keypress-contingent tones, subjects might have been surprised and curious about what function these tones might have. Accordingly, the priming effect might not so much reflect automatic integration but rather a strategy to distract oneself in a boring task. However, as the learning curves across up to five sessions showed, tone priming was not strongly affected by practice, even though the size of the effect was very small from the beginning. On the one hand, this means that the priming effect is not a short-lived, curiosity-based effect but reflects the acquisition of stable associations. On the other hand, the fact that practice beyond the first session did not increase the priming effect any further suggests that action effects are learned relatively quickly. In fact, another study of ours that varied the amount of practice in smaller steps showed that priming effects are enhanced by up to 100 pairings of action and action-contingent effect but not any further.

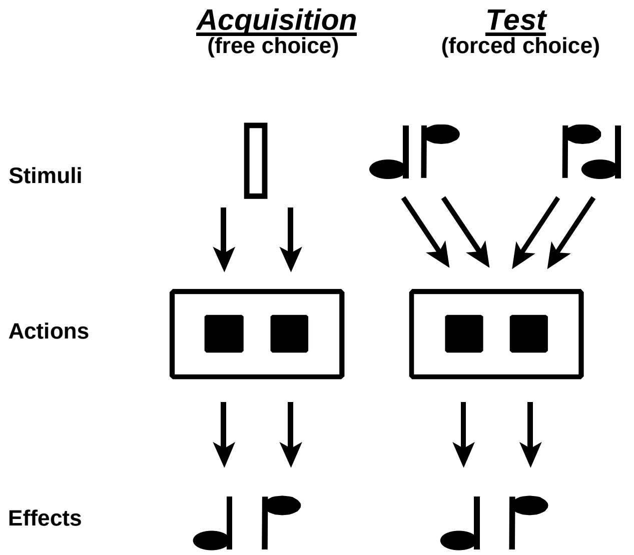

Figure 5. Basic design of Elsner & Hommel (1999a, Exp. 1).

One problem with the priming design is that it may be sensitive to classical stimulus-stimulus conditioning. Note that the responses were mapped onto the same letters in both the acquisition and the test phase. Accordingly, the theoretically interesting relationship between responses and response-contingent tones was completely confounded with the less interesting relationship between these tones and the letters serving as relevant stimuli. Therefore, better left-hand keypress performance, say, with low-pitched tones may not be due to the compatibility between tone prime and integrated effect tone but to an association between the letter O and the low tone. To rule that out we developed a task variant that no longer used discriminative stimuli in the acquisition phase.

In that experiment (Elsner & Hommel, 1999a, Exp. 1), we changed the acquisition phase into a free-choice task (see Figure 5). That is, a single, nondiscriminative stimulus appeared in each trial to trigger a freely chosen left or right keypress—subjects were only asked to use the two keys about as often across the experiment. As before, each keypress produced a low or high tone as action effect. In the test phase, the low and high tones were (also) used as imperative stimuli. In one group, the tone-key mapping was *consistent* with the key-effect mapping of the acquisition phase. That is, if left and right keys produced low and high tones, respectively, the consistent-mapping group would now press the left key in response to a low tone and the right key to a high tone. In another group the mapping was *inconsistent* with the learning experience. That is, if left and right keys produced low and high tones in the acquisition phase, the inconsistent-mapping group would now press the left key in response to a high tone and the right key to a low tone. If the subjects had not acquired the irrelevant key-tone associations in the first phase, and/or if these associations were not bilateral (i.e., work "backwards"), performance in the consistent- and inconsistent-mapping groups should not differ. However, if actions and effects had been integrated automatically, the consistent group should be able to make use of the already acquired tone-key associations and, thus, outperform the inconsistent group. Indeed, we observed much faster responses in the consistent- than the inconsistent-mapping group, suggesting that bilateral tone-key associations had in fact been automatically acquired. Interestingly, this was also the case in an extinction condition, where keypressing no longer produced tones in the test phase. That is, action-effect relationships are not only learned automatically, but they are also relatively resistant to extinction.

Both the automaticity of acquisition and the resistance of action-effect relationships makes sense. As pointed out in the introduction, intending a goal-directed action presupposes knowledge about which effects an action produces, hence, acquisition of that knowledge necessarily precedes its use. If knowledge acquisition were not automatic, it could only take place when the knowledge is actually needed—a rather inefficient strategy. In contrast, automatic acquisition equips a perceiver/ actor with a continuously growing database containing an increasing number of action effects, that is, with expanding knowledge about potential action goals. However, actions do not always and under all circumstances lead to exactly the same action effects. Walking in the dark does not provide the same rich flow of visual information about the dynamic relationship between walker and environment as walking in daylight does. If the lack of visual action effects would lead to immediate extinction, all the respective knowledge would be lost and the walker would be very surprised to find walking-related optical flow when the lights go on. This would be unreasonable and is not what we experience under changing environmental or personal conditions, which suggests that associations between actions and action effects (or their cognitive representations) are relatively stable.

CONDITIONS OF ACTION-EFFECT LEARNING

If action-effect learning is as simple and automatic as we assume, it is likely to underlie situational constraints, especially to those known to apply to other domains of human learning and especially to those known to affect other forms of action-effect acquisition. Up to now, we have investigated three potentially important constraints on action-effect learning: contingency, temporal contiguity, and belongingness.

The perhaps most central constraining factor in learning is the *contingency* between actions and their outcomes. In humans, contingency is commonly investigated in studies on causal judgments. In such studies subjects perform certain actions that may or may not produce certain outcomes, such as light flashes or explosions in a video game. Typically, the contingency or contiguity between actions and outcomes are manipulated and the subjects are asked how strong they would judge the causality between them. Interestingly, the pattern of such judgments are quite similar to results from studies on animal learning, which has been taken to indicate that the underlying learning mechanisms are equivalent (e.g., Shanks & Dickinson, 1987; Wasserman, 1990). Although first studies did not find evidence that humans are capable of making realistic causality judgments (Jenkins & Ward, 1965; Smedslund, 1963), recent methodological improvements have given rise to a more optimistic picture. That is, the higher the actual contingency between actions and their effects, the stronger the judgment about their causal relationship (e.g., Allan & Jenkins, 1980; Shanks & Dickinson, 1987; Wasserman, 1990).

For our own approach, these findings suggest that action-effect learning may take place with high but not with low contingency between action and effect. We (Elsner & Hommel, 1999b) investigated this assumption by using the basic design of Elsner and Hommel (1999a, see Figure 5). Four groups of subjects practiced the free-choice tone-production task with key-tone contingency varying from .30 to .60 and then worked through the same test phase as the subjects in the Elsner and Hommel (1999a) study. As expected, the standard mapping-consistency effect indicative of key-tone association was reliable only with high contingency (i.e., in the .60 group) but not with low contingency (i.e., in the .30 group). That is, action-effect relations are only acquired if the underlying contingencies are considerable, a finding that fits well with the results of the causality-judgment studies.

A second potentially important factor constraining learning is *temporal contiguity*, that is, the temporal delay of an outcome event to the action it depends on. In animal studies, performance is known to decrease as the temporal delay of response outcomes to responses increases (Renner, 1964; Tarpy & Sawabini, 1974). In humans, there is again some positive evidence from causality-judgment studies (e.g., Reed, 1999). Motivated by that, Elsner and Hommel (1999c) investigated the role of contiguity in action-effect association. Again, the basic design of Elsner and Hommel (1999a) was employed, but now in the acquisition phase the effect tones were delayed by 50, 1000, or 2000 ms, in different groups. Performance in the test phase was a direct function of contiguity: The mapping-consistency effect decreased as the action-effect delay increased and was reliable only with 50 and 1000 ms delay but not with the 2000 ms delay. Thus, on the one hand, temporal contiguity does not need to be perfect for action-effect learning to occur, which agrees with Hommel's (1999) observation of considerably-sized integration windows in stimulus-response learning. On the other hand, however, some degree of contiguity is clearly necessary.

A third factor we investigated has been termed *belongingness* (e.g., Thorndike & Lorge, 1935). This concept is based on the idea that, given the already existing knowledge of a learner, some relationships between actions and effects may be more natural or obvious than others. For instance, when uttering a cry one may expect all sorts of auditory effects, depending on the acoustic characteristics of the environment, but being exposed to some sort of gustatory effect of one's own cry would certainly be a very surprising experience. Likewise, increasing the intensity of the cry would be expected to produce more but not less intense effects, and so forth. It is conceivable that the plausibility of novel action-effect relationships has an impact on whether or how quickly the latter are acquired, so that we wanted to know more about the role of plausibility in action-effect learning.

In a first experiment on this topic, we used a manual eight-choice reaction-time task. In the acquisition phase subjects responded to color stimuli by pressing one of eight horizontally arranged keys that were operated by four fingers of each hand. In a *plausible-mapping* group, the eight keys functioned like a C major keyboard, so that pressing a key produced a C, D, E, F, G, A, H, or C', from left to right. In an *implausible-mapping* group, the key-tone mapping was also fixed but arbitrary (E, F, C, D, H, C', G, and A), and in a *neutral* group, each key produced the same effect (F). The implausible key-tone mapping yielded slightly worse performance than the other mapping; yet, this effect was statistically unreliable and reversed in the errors. That is, the acquisition phase did not provide unequivocal evidence for a critical role of action-effect plausibility. In the test phase, subjects received a tone-key mapping that was either plausible (i.e., C, D, E, F, G, A, H, and C' signaling the eight keys from left to right) or implausible (i.e., E, F, C, D, H, C', G, and A signaling the eight keys from left to right). Apart from a less interesting main effect of mapping, there was an interaction between the already acquired key-tone mapping and the tone-key mapping in the test phase: Whereas preexperience had no effect with the implausible mapping, it did affect performance with plausible mapping. Although this interaction failed to reach significance, we do take these results as a preliminary hint to a possible mediating role of belongingness or plausibility in action-effect learning.

Taken altogether, the available findings suggest that action-effect integration requires a minimum degree of action-effect contingency, and a temporal distance between action and effect of less than 2 seconds. There is also some indication that the plausibility of the action-effect relationship supports and enhances action-effect learning, although this issue needs to be investigated more deeply. These findings are in good agreement with those observed with other types of learning, which suggests that action-effect acquisition is based on the same learning mechanism as classical stimulus-stimulus and stimulus-response learning.

CONTROL OF AUDITORY ACTION EFFECTS

We have discussed substantial evidence that cognitive codes of actions and their effects are automatically integrated, if only some degree of contingency and contiguity is given. However, demonstrating that such action-effect associations are acquired is one thing but showing that these associations actually mediate the selection and control of action is another. So, how can we know that actions are really selected on the basis of their associated effects?

True, preliminary evidence can be taken from the reported priming and mapping effects. These effects do not only indicate that action-effect learning occurred, they also show that the speed of response selection is influenced by the presentation of response-compatible or incompatible action effects. Obviously, such influence presupposes some flow of activation from effect representations to response codes, such as shown in Figure 6. That is, when a left-hand keypress had produced a low tone and a right-hand keypress a high tone, presenting a low tone somehow activates the corresponding action concept (here for Action 1) and the motor codes it contains. However, our priming and mapping effects represent quantitative influences on selection processes—facilitation or delay of selection—but, apart from some minor effects in the error rates, they do not yet show that the *outcome* of action control can depend on the activation of action concepts and action-effect representations. Yet, if action concepts really mediate intentional action control, such qualitative effects should be demonstrable.

In a sense, some hints to a qualitative effect on action control can be taken from the study of Hommel (1993). He used a Simon task, in which subjects responded to nonspatial features (here: tone pitch) of stimuli that randomly appeared at the left or right side of the subject. If we assume that low pitch signals a left-hand action and high pitch a right-hand action, as actually was the case in the Hommel study, the mediating action concepts should have looked like those shown in Figure 6. As suggested by this sketch, the nominally irrelevant stimulus location should affect response selection. If the low tone comes up on the left side, it should activate the corresponding action concept via both the pitch code and the location code, so that motor pattern m_1 should be activated more quickly than if the low tone would have appeared on the right side. In other words, spatial correspondence between stimulus and response should lead to faster reactions than noncorrespondence, which is actually the case (the so-called Simon effect; for an overview, see Lu & Proctor, 1995).

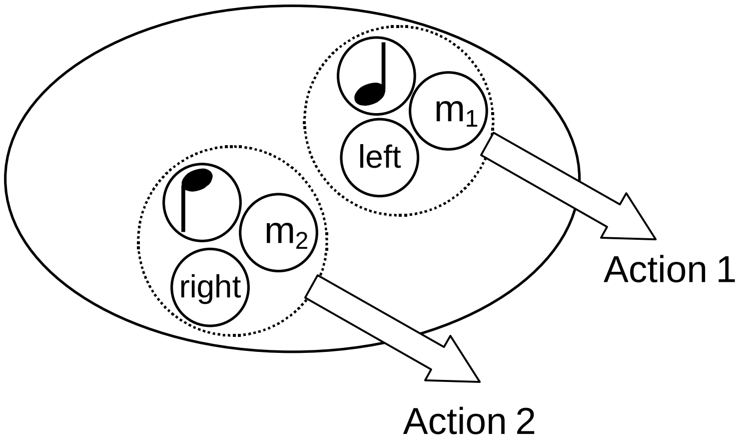

Figure 6. Hypothetical, simplified action concepts for a left-hand keypress producing a low tone and a right-hand keypress producing a high tone.

But assume now that the left-hand response flashes a light on the right side, and vice versa. This would mean that the concept of Action 1 would include a left keypress or finger code and a right light code, whereas the concept of Action 2 included a right keypress or finger code and a left light code. In other words, each action would be coded in terms of left *and* right. In such a situation the actual coding should depend on the actor's intentions, hence, on the action effects (keypress or light flash) he or she *wants* to produce. To manipulate these intentions, Hommel (1993) asked one group of subjects to "press the left/right key" and another group to "flash the right/left light" in response to the tone pitch. With keypressing intentions, subjects should be faster with tone-key correspondence, as this would mean correspondence between stimulus and intended action effect or action goal. However, according to the same logic, subjects with light-flashing intentions should be faster with tone-light correspondence, although this meant tone-key *non*correspondence. Indeed, there was a pronounced benefit with stimulus-key correspondence in the key-instruction group, and this effect was completely reversed in the light-instruction group. That is, in both groups performance was best when the stimulus shared its spatial feature with the event that the subjects intended to produce. Obviously, then, stimuli are able to activate particular action concepts, and the effect of this activation depends mainly on the perceiver/actor's intentions, hence, on the intended action effect.

Further, and even more direct, evidence for a qualitative impact of action effects on action control has been gathered by Elsner and Hommel (1999a, Exp. 2-4). They modified the design shown in Figure 5 by replacing the forced-choice task in the test phase by a free-choice task (see Figure 7). That is, after having learned the key-tone mapping in the acquisition phase, subjects were in each trial presented with a low or high tone that they responded to by a freely chosen left or right keypress—they were only asked to use both keys. The rationale for this experiment was straightforward. If the subjects would actually select their actions by activating action-related effect codes, presenting those effects should lead to an observable bias of their choices. That is, in the presence of a particular tone subjects should tend to choose the response that had produced the tone in the acquisition phase.

Indeed, this is what happened: Subjects chose the tone-associated response much more often than the alternative response. This was also true when the keypresses no longer produced the tones in the test phase, hence under extinction conditions. To rule out that these biases are based on systematic strategies, Elsner and Hommel (1999a) repeated the

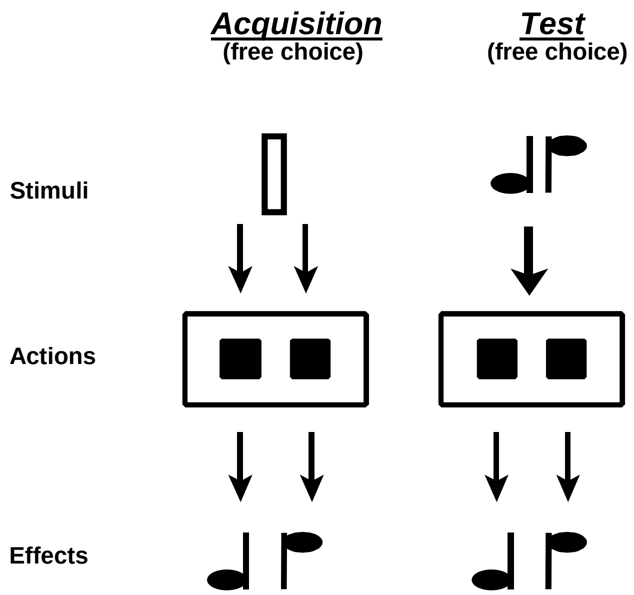

Figure 7. Basic design of Elsner & Hommel (1999a, Exp. 1).

experiment under a heavy working-memory load (backward counting). Yet, the results were exactly the same: more choices of tone-consistent than inconsistent responses. This means that presenting a possible goal (i.e., an "intendable" action effect) biases the perceiver to choose that goal and to perform the action that he or she knows to be functional in attaining it. Thus, action selection is mediated by action-effect representations.

TOWARD AN INTEGRATED MODEL OF HUMAN BEHAVIOR

We have argued that an apt characterization of human behavior may not begin with the stimulus as the first link in a causal stimulus-response chain but, rather, with goal-directed action that aims at the production of stimuli. Hence, somewhat counter-intuitively, action may come first, and perception second. We have presented a very first sketch of a simplified, preliminary model of how intentional action may evolve in an individual, how new information is acquired and integrated, and how the integrated knowledge is used to perform intentional actions and to produce desired stimulus events. According to this model, perceptual representations are not separated from action-related information, but are integrated with this information into action concepts, that is, into coherent sensori-motor structures. Our approach recognizes that perceptual events are best characterized in terms of what action they afford, as emphasized by Gibson (1979), Wolff (1987), and other ecologists. Indeed, knowledge about perceptual attributes as such is of little ecological and practical use unless one knows about the action-related opportunities these attributes offer to the perceiver. As trivial as this insight may seem, the interconnectedness of perception and action is still widely neglected in current models and theories—so that it takes no wonder that they all begin their analysis with the stimulus. However, we think that 103 years after the publication of Dewey's warning, it is about time to come up with a more realistic, integrated model of human behavior that recognizes and theoretically incorporates both halves of the reflex arc.

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