Intentional Control of Automatic Stimulus-Response Translation

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Human information processing is commonly conceived of as an orderly sequence of processing steps that transform stimulus energy impinging on our sensory organs into a coherent set of muscle contractions. A central role in relating the output of perceptual stages to corresponding response patterns is attributed to the stage of stimulus-response (S-R) translation, and it is this stage that is commonly associated with intentional control. However, intentional control is far from being perfect. In fact, older investigations on the interplay between will and habit using Ach's combined method as well as newer experiments on the Simon effect demonstrate that task-irrelevant stimuli can activate responses automatically if the corresponding S-R pair is highly overlearned and/or compatible. Although the underlying translation processes sometimes counteract the intentions of the perceiver/ actor, they are not independent from these intentions either. In particular, "automatic" S-R translation can be shown to depend on the perceiver/actor's interpretation and coding of stimuli and responses, on his or her task goals, on the degree of task preparation, and on task-related strategies. Apparently, intentional and automatic processes do not directly compete for S-R translation; rather, intentional processes seem to implement a task set that enables and configures automatic translation processes.

Introduction

Human behavior is not so much driven by immediate stimulation from the environment, but steered by intentional states representing short- and long-term goals. Of course, this does not imply that environmental information is irrelevant for action control. In fact, adaptive action does not only require intentions to take into account the environmental conditions for and the context adequacy of action, it also heavily relies on the availability of environmental information for on-line control. That is, to successfully tailor an action to a given situation there must be a whole wealth of interactions between internal and external states, presumably on many different levels at the same time.

Although intentional action is almost by definition bound to the conscious representation of the action goal(s), many processes subserving the realization of this goal are not. In fact, authors such as Lotze (1852) or James (1890) have claimed that *only* action goals can be consciously represented, while the remaining processes are more or less automatic consequences of the assumed intentional state—processes that are not accessible to consciousness and, thus, not under its direct control (for an elaboration of this theme, see Baars, 1987). Meanwhile, it has become less fashionable to speak of phenomenal experience and subjective states, and so the functional aspects of what was previously discussed under the heading of conscious versus unconscious states was translated into the dichotomy of intentional (or controlled) versus automatic processes.

This chapter deals with the relationship and the interplay between intentional and automatic processes in the translation of environmental information into overt action. In everyday action, this interplay produces perfect outcomes most of the time: Actions typically come out as wanted, and they do so very efficiently. Although this is certainly a great achievement of (not only) human evolution, failures of this interplay are of greater theoretical interest as they tell us something about the structure and the modes of operation of the underlying cognitive mechanisms. The most obvious expressions of such failures are action errors, and there is an increasing literature on which kinds of action errors are likely to occur under which circumstances (e.g., Heckhausen & Beckmann, 1990; Reason, 1990). Milder forms show up as hesitations in reaction time experiments in the face of ambivalent stimuli. A well-known example is the Stroop task, where subjects are to name the ink of color words (Stroop, 1935). As one may imagine, responding is much easier in terms of reaction times and errors if the meaning of the word is congruent with the to-be-named color and the required response (e.g., the word RED written in red ink) than if it is not (e.g., the word GREEN written in red ink). Obviously, presenting an incongruous word leads to a conflict between the intended translation of stimulus color into the appropriate color-naming response and the unintended, but highly overlearned and automatized translation of the word into the corresponding color name. Although conflicts of this sort are rarely observed in everyday life, where intentional and automatic processes usually complement each other, they are highly interesting for the study of intentional and automatic processes. If it were possible to selectively influence the intentional or the automatic part of such a conflict, we would be able to experimentally dissociate and study them—or at least their relative contribution—in isolation.

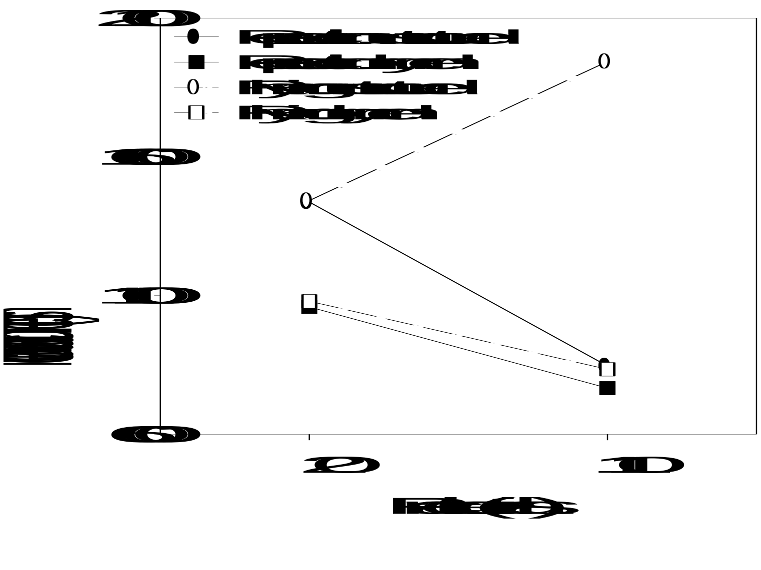
I will describe two paradigms that turned out to be very helpful in separating and dissociating intentional and automatic processes of S-R translation. The first is a rather old and unknown one—the so-called combined method, developed by Narziß Ach, which requires subjects to overcome overlearned, automatic response tendencies. The second is more recent and better known—the Simon effect and its variants, which makes use of people’s automatic tendency to respond to stimuli in a spatially corresponding manner. I will show that and how both paradigms are well suited to analytically dissociate intentional and automatic processes of S-R translation, so that their characteristics can be studied more or less independently. Eventually, however, I will also point out that the relationship between intentional and automatic translation processes is much more intricate than available approaches seem to admit, and I will sketch how a more realistic approach may look like.

Dissociating Intentional and Automatic Stimulus-Response Translation

Ach's Combined Method and the Interplay of Will and Habit

Recent reviews dealing with the relationship and interactions between intentional and automatic S-R translation processes (e.g., Allport, Styles, & Hsieh, 1994; Ouellette & Wood, 1998; Monsell, 1996; Shallice, 1994) typically assume that the systematic treatment of this issue began somewhere in the seventies, motivated by the classical papers of Atkinson and Shiffrin (1968), Posner and Snyder (1975), and Shiffrin and Schneider (1977). In fact, however, the question of how "will" and "habit" (the terms preferred in the earlier days) interact launched extensive experimental research and theoretical work between 1910 and 1935 already, with Narziß Ach and Kurt Lewin being the main opponents in a furious debate (for a less selective English overview of this German literature, see Gibson, 1941).

The debate was initiated by a book of Ach (1910), in which the author proposed what he called the *combined method* ("kombiniertes Verfahren") as a means to experimentally investigate intentional processes (i.e., the will). These processes can be studied best, so he argues, if the intention to act is opposed to an overlearned habit that calls for another, conflicting action—not unlike the Stroop task. Consequently, the combined method was designed to induce a habit in a practice phase, which then had to be overcome in a test phase. A typical practice phase required subjects to read lists of consonant-vowel-consonant nonsense syllables that were structured in particular ways. Some lists consisted of rhymed syllable pairs (e.g., "zup, tup, tel, mel, ..."), some of pairs with the first and second consonant exchanged (e.g., "dus, sud, rol, lor, ..."), and some were unstructured. Reading those lists again and again was assumed to form increasingly strong associations between succeeding list members, so that seeing and reacting to the syllable "zup" from the rhymed list, say, would automatically evoke the next response "tup", and so forth. After several days of practice subjects were presented with, for instance, the first, third, fifth, ..., syllable from the learned lists (i.e., the first members of the syllable pairs in the rhymed and rearranged lists), or with new syllables, and were asked, in separate blocks, to respond to that stimulus with either a rhymed word, the syllable with the two consonants exchanged, or any word (so-called



"reproduction task").

Figure 1: Median reaction times for syllable reproduction (free association) and syllable rhyming in Ach (1910, Designs I and II), as a function of the syllables' previous list membership (rhymed vs. unstructured list) and practice (20 vs. 110 repetitions of list reading). Data are taken from, and averaged across, subjects B-E.

Figure 1 shows typical results from four subjects working on a restricted version of the combined method. First look at the findings obtained with little practice in list reading before (and during) the test phase (20 repetitions overall, see dark bars). Although syllables from rhymed lists yield better performance than those from unstructured lists, this is true for both the reproduction task and for the rhyming task, hence there is no specific effect of learning on performance. Things are different, however, if practice increases (110 repetitions overall, see bright bars). In the reproduction task, practice has improved performance for both kinds of syllables, but more so for those from the unstructured list. The opposite pattern is obtained in the rhyming task, where performance improved with practice only with syllables from rhymed lists but was impaired for syllables from unstructured lists.

According to Ach, this outcome pattern reflects the conflict between will and habit. Practice in pairing particular stimuli with particular responses should strengthen the associations between the corresponding stimulus and response representations, so that presenting the stimulus another time will automatically induce the tendency to repeat the associated response. To overcome this habit, some amount of "will power" is required, the more the stronger the respective S-R association is. As applying will power arguably takes time, reaction time should in fact increase with increasing conflict between willed and automatically activated response, hence the better practiced a conflicting response to a given stimulus (or the underlying S-R association) is. High degrees of practice should also call up habit-related errors—a prediction that is also nicely confirmed by Ach's findings.

Following the pioneer study of Ach (1910), the combined method was continuously improved and refined, mostly by Ach's students (for a review, see Ach, 1935). For instance, Glässner (1912) showed that syllables from a previously learned fixed-order list (i.e., items which are presumably highly associated) facilitate performance in a reproduction task ("name any associate") but impair performance in a rhyming task, as compared to syllables from a varied-order list (i.e., weakly associated items). Müller (1932) manipulated the strength of S-R associations by varying the type of interitem relationship, ranging from arbitrary pairings (e.g., "pin-jor", "wad-tim") to identical syllables combining to a legal word (e.g., "bon-bon", "dum-dum"). As expected, reproduction per-formance monotonously increased with hypothesized association strength, whereas performance in a task requiring a novel response to each item ("replace vowel by 'au'") showed the opposite effect.

The theoretical considerations of Ach and his students did not go without challenge, however. In his dissertation work, Lewin (1917, 1922a, 1922b) not only made a (rather unsuccess-ful) attempt to replicate Ach's findings with the original combined method, he also investigated the impact of practicing the rhyming and rearranging of syllables on their later practice-consistent versus inconsistent use in rhyming and rearranging tasks. Whereas the original method required subjects to read through structured or unstructured syllable lists in order to induce associations between succeeding list members, Lewin attempted to induce those associations by having subjects actually perform rhyming and rearranging tasks on syllables. So, instead of presenting his subjects with pairs of rhymed or rearranged syllables, he presented only one syllable and asked the subjects to produce the rhyme or rearranged member themselves. There were several blocks of practice for the rhyming and the rearranging task. Some syllables only appeared under the rhyming instruction, some only under the rearranging instruction, and some under both instructions (control items). After nine days of practice, all syllables were tested under either instruction. However, there was hardly any difference between reaction times and error rates for practice-consistent and practice-inconsistent task instructions, suggesting that S-R associations were not formed or not operative under these circumstances (Lewin, 1922a). Interestingly, though, practice consistency did have the predicted effect if during practice the control items were not presented among the consistent items (Lewin, 1922b).

Lewin (1922b) attributed his findings to different task sets, presumably induced by the occurrence versus non-occurrence of control items. Note that, in the practice phase, consistent items always validly specified the corresponding task and, therefore, the correct response. In contrast, control items can occur under either instruction, so that each of these items becomes associated with two tasks and two responses. Consequently, Lewin argues, if no control items appear during practice subjects can rely on the automatic retrieval of responses through stimulus presentation, that is, they can follow where their habits lead them. If they adopt this kind of automatic mode, the presentation of inconsistent items in the experimental test phase is likely to result in the automatic retrieval of the practiced, but incorrect responses, this leading to many errors and/or considerably prolonged reaction times—the outcome predicted by Ach's theory. However, if ambivalent control items do occur during practice, subjects are unable to rely on automatic retrieval, because this would produce too many errors. Therefore, they adopt a more controlled S-R translation mode, which is much less susceptible to the presentation of inconsistent stimuli. If so, automatic S-R translation processes would not be as independent from intentional processes as Ach's original approach suggests. In fact, it may be exactly those intentional processes that actually set the stage for automatic translation.

It should be noted that the empirical basis for Lewin's arguments is not watertight. Simoneit (1926) and Ach (1935) pointed out that having people not read through pairs of syllables but practice a particular task is likely to call up task-specific strategies that may work against strong interitem associations. For instance, practicing the rhyming task might lead one to focus onto the rhyming-relevant letter position only and to ignore the remaining letters, which may not allow for strong associations between the whole stimulus syllable and the response. In fact, Simoneit (1926) demonstrated pronounced practice-consistency effects even in Lewin's original design by only increasing the frequency of task switching, that is, by introducing a condition that is likely to counteract the development of task-specific strategies. So, it would be premature to settle the Ach-Lewin debate without further systematic experimenting, the more so as the original findings are based on very few (often single) subjects without any formal statistical testing. However, we will also see that the figures of thought that arose in this debate are still topical today, after having been rediscovered, if not reinvented, several times already. Moreover, the available studies also demonstrate that S-R translation is not only determined by intentional processes, but strongly affected by overlearned, automatic translation processes as well. Obviously, these automatic processes can be experimentally manipulated and even induced independently from intentional processes. Nevertheless, whether their behavioral effects are also independent from intentions remains to be seen.

The Simon Effect and the Rediscovery of Dual Routes

Ach's combined method was designed to bring intentional and automatic processes into conflict, so that their relative contribution to action control can be determined, compared, and investigated. A very similar method was discovered accidentally by Simon and Rudell (1967). While exploring the role of handedness and left-vs.-right-hemispheric processing in man-machine interactions, they presented the words "left" and "right" to signal left- and right-hand keypressing reactions. To manipulate the cortical hemisphere responsible for stimulus processing, the words were presented randomly to the left or right ear through earphones. Surprisingly, stimulus location strongly interacted with response location, such that left responses were much faster if the command signal was presented to the left than the right ear, whereas right responses were faster with right-side presentation. Follow-up studies by Simon and colleagues demonstrated that this effect is much more general than one might assume (for an overview, see Lu & Proctor, 1995).

Similar effects were observed with tone pitch (Simon & Small, 1969), visual color (Craft & Simon, 1970), or other nonspatial features as relevant stimulus, showing that what matters is the relationship between (irrelevant) stimulus location and (relevant) response location, and not that between (relevant) stimulus meaning and (irrelevant) stimulus location. Furthermore, hemisphere-specific processing does not substantially contribute to the effect, as it can be obtained even if both stimulus locations fall into the same visual field (e.g., Craft & Simon, 1970) or if unimanual pointing responses are employed (e.g., Simon, 1968).

Over the years, several explanations have been suggested to account for the “Simon effect”, as it is called since Hedge and Marsh (1975), but the differences between existing models are rather subtle (see Hommel & Prinz, 1997, for a recent overview). The very first account proposed by Simon (1968, 1969) attributes the effect to a “natural tendency” to respond toward the source of stimulation. If, for instance, a signal indicating the left response appears on the right side, this automatically induces the tendency to respond “toward the right side”. As this tendency is misleading, it needs to be overcome by time-consuming processes, which are not required if the signal had appeared on the response-corresponding left side. Although this approach goes not much further than to redescribe the empirical findings, it is interesting to note that it follows the same line of reasoning than that by Ach (1910): Stimuli might activate overlearned (or even inborn) habits that compete with intentional translation processes for action control. If such a description really captures the essence of the Simon effect, the Simon task might be a useful tool to investigate the relationship and interplay between automatic and intentional processes of S-R translation.

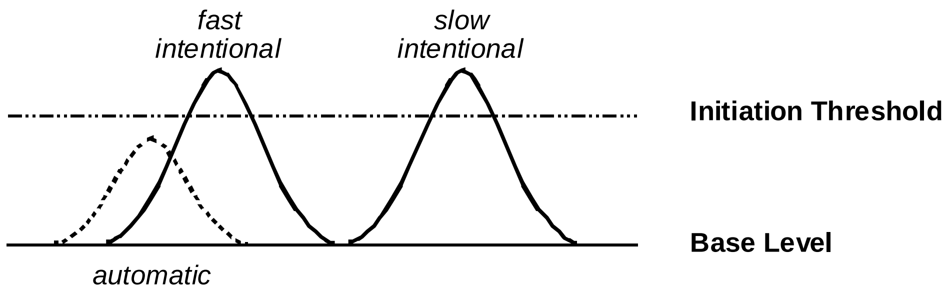
In fact, the distinction between parallel automatic and intentional routes from stimuli to responses plays a prominent role in most models on the Simon effect and similar phenomena, the perhaps most comprehensive approach being the dimensional-overlap model proposed by Kornblum and colleagues (Kornblum, 1992, 1994; Kornblum, Hasbroucq, & Osman, 1990). According to the model, the intentional route works as assumed by most other information processing models, with stimuli being encoded and translated into the correct response, followed by retrieval and execution of the corresponding motor program. The automatic route comes into play if stimulus and response features overlap. Then the stimulus will automatically prime the feature-overlapping response, whether this response is correct or not. If it is correct, the same motor program is activated via two routes, resulting in a speed-up of program retrieval. But if it is the wrong response, two responses will be active and compete for execution, which calls for a time-consuming conflict-resolution process that delays eventual responding.

Although the details of this model are still under debate and in need of clarification, its basic assumption of parallel intentional and automatic routes of S-R translation are shared by many other models in the S-R compatibility domain (e.g., Barber & O’Leary, 1997; De Jong, Liang, & Lauber, 1994; Eimer, Hommel, & Prinz, 1995; Hommel, 1993a). This is the more interesting as those dual-route models can be seen as mere translations (though with somewhat more detail) of Ach’s theory on the relationship between will and habit from an outdated, phenomenologically inspired language into more fashionable information-processing terms. Of course, the theoretical focus differs slightly between these approaches: Ach was mainly interested in practice-induced automatic translation, whereas compatibility approaches rather focus on automaticity due to feature overlap. However, even though it makes sense to treat practice and feature overlap as distinct factors capable of producing automatic response activation (Hommel, 1998; Kornblum et al., 1990), this has no obvious implications for how one conceives of the relationship and interplay between intentional and automatic translation processes as such.

Strong support for the dual-route conception comes from psychophysiological studies. For instance, presenting a lateralized stimulus has been found to prime the corresponding response up to a level that can be observed in lateralized readiness potentials (LRPs; De Jong et al., 1994; Sommer, Leuthold, & Hermanutz, 1993), electromyographical recordings (Zachay, 1991), and registrations of subthreshold movements (Zachay, 1991)—even when stimulus location is completely irrelevant and even if the correct response is eventually performed. Furthermore, Eimer

(1995) showed that merely presenting cues with a spatial meaning (i.e., left- or right-pointing arrow-heads) activates the spatially corresponding response, and this is true even if those cues are not consciously perceived (Eimer & Schlaghecken, in press; Leuthold & Kopp, 1998). So, there is little doubt that stimuli can be translated into response activation even if this runs counter to one’s current intention to act, this strongly suggesting parallel intentional and automatic translation.

More evidence on the existence of more than one route from stimulus to response comes from studies on the temporal dynamics of the Simon effect. In several experiments in my lab I consistently observed that the size of the Simon effect decreases with increasing task difficulty. For instance, when I varied the lateral retinal eccentricity of a form stimulus from 0.2° to 6.1°, I found the benefit of S-R correspondence over noncorrespondence to decrease from 23 to -5 ms (Hommel, 1993a: Exp. 2)—a rather counterintuitive result. One possible explanation, also suggested by De Jong et al. (1994), assumes a spontaneous decay of automatically induced response activation. Figure 2 shows the logic of this explanation. Assume that presenting a lateralized stimulus automatically activates the corresponding response, but this activation quickly decays over time, just as indicated by the leftmost activation function (see broken lines) in Figure 2. If the relevant stimulus feature is easy to process, it is soon translated into the correct response, as indicated by the activation function in the middle (fast intentional). As the activation of this response temporally overlaps with the automatically activated response, a pronounced Simon effect is obtained: fast responses if both activations refer to the same response, slow responses if they refer to different responses. However, if one makes processing the relevant stimulus feature more difficult (e.g., by presenting it at retinal locations with suboptimal spatial resolution), intentional S-R translation will be delayed, as indicated by the rightmost activation function in Figure 2. With increasing delay the temporal overlap of intentional and automatic activation decreases, so that it becomes more and more likely that the automatically induced response activation has already decayed at the time the



response is selected. If so, automatic response activation does no longer affect performance, hence no Simon effect.

Figure 2: A temporal-overlap model of the Simon effect. Fast automatic translation produces temporary, subthreshold stimulus-induced activation of the corresponding response, followed by quick decay. If intentional translation is fast, there is temporal overlap of automatic and intentional response activation, this yielding facilitation if both converge onto the same response, and conflict if not. If intentional translation is slow, there is no overlap and, hence, no facilitation or conflict.

============= FIGURE 2 ==============

According to this temporal-overlap account, intentional and automatic translation processes are independent and can thus be experimentally manipulated separately. This allows for a number of predictions, some of which have already been empirically confirmed. First, one would expect that any manipulation that prolongs the processing of the relevant stimulus feature and/or the activation of the correct response (without affecting location processing) reduces the size of the Simon effect. In fact, marked reductions of effect size (up to the elimination of the effect) have been demonstrated as a consequence of reducing the visual quality of the stimulus through pattern masking (Hommel, 1993a), of making the alternative stimuli less discriminable (Hommel, 1994; Lu & Proctor, 1994), of increasing the size of the memory set the stimuli belong to (Hommel, 1995), or of introducing a secondary task (McCann & Johnston, 1992).

Second, the Simon effect should not only decrease between conditions of different difficulty, but also within a condition, namely from fast to slow responses of the same subject. That is, if we compute the Simon effect separately for the lower and the upper tails of individual reaction-time distributions, we would expect the Simon effect to be the smaller the longer the reaction times are. In fact, the effect size can be shown to continuously decrease from fast to slow portions of the reaction time distribution (De Jong et al., 1994; Eimer et al., 1995; Hommel, 1997; see, however, Zhang & Kornblum, 1997, for some caveats as to this kind of analysis).

Third, if the decrease of the Simon effect with increasing task difficulty is really due to the spontaneous decay of automatic response activation, one should be able to work against the effect's decrease by introducing task features that make the location of the stimulus more relevant to the task. Again, the evidence is positive. If one asks the subjects in a Simon task to report the location of the stimulus after each trial, the effect gets even larger than normal (Hommel, submitted a; Simon, 1982).

Fourth, the temporal-overlap model suggests that, under certain stimulus conditions, one should be able to completely invert the Simon effect's temporal dynamics. In the standard task, the relevant stimulus feature often takes much longer to process than the irrelevant location information, which is why the "intentional" function in Figure 2 begins to rise only some time after the "automatic" function. However, what if we came up with a relevant stimulus feature that can be processed even faster than stimulus location? Then, the intentional function would start before the automatic one, so that the effect of S-R correspondence should be the more pronounced the longer the relative reaction times are—hence increase from the lower to the upper tail of the reaction time distribution. This prediction is supported by Hommel (1996: Exp. 1), where subjects responded to the mere onset of a lateralized stimulus by performing an already prepared response. Reaction times were not only very quick, they also showed the expected distribution, with longer reaction times being associated with a larger correspondence effect.

Taken in sum, there is ample evidence from Simon tasks that intentional and automatic processes coexist and compete for action control. They are likely to exhibit different time courses—depending on the particular stimulus features and task context—that can be dissociated and selectively manipulated. Although the genesis of automatic translation processes due to S-R feature overlap on the one hand and those due to S-R practice on the other may be different, the implications from compatibility studies and from learning studies nicely converge onto the same theoretical conclusions.

Intentional Control of Automatic Translation Processes

The evidence discussed so far clearly rules out the perhaps more intuitive idea that S-R translation is a direct reflection of human will. Rather, it seems that human performance emerges from the interplay of both intentional and automatic translation processes. But does this necessarily imply that intentional and automatic translation processes are of comparable status except that the former are more related to intentions than the latter? Is it really true that automatic processes are autonomous operations that do in no way depend on the intentional states of an acting person, as assumed, among others, by Ach (1910), De Jong et al. (1994), or Kornblum and coworkers (1990)? I will now go on to discuss several empirical reasons—mostly taken from S-R compatibility research (for a broader review, see Hommel, in press)—to doubt the assumption that automatic translation is completely independent from intentions. There is evidence that automatic translation is a more or less direct function of intentional preparation, suggesting that intentional processes do not really compete with, but rather set the stage for automatic processes. Hence, in the words of Bargh (1989), automaticity may (always?) be conditional automaticity, just as suspected by Lewin (1922b).

To begin with, let me use the example sketched in Figure 3 to organize the further discussion. It refers to a typical situation in a Simon task, which in this case requires pressing a left versus right key in response to the green or red color of a visual stimulus, respectively. Let us now assume that a red stimulus appears on the left side, an incompatible situation that induces competition between the correct response activated via the intentional route from color to response and the automatically activated, but incorrect stimulus-corresponding response. Logically, there are at least three ways in which translation via the automatic route could be affected by, or depend on, intentional processes. First, intentional processes may be able to influence, or even to determine, whether and how stimuli are cognitively coded (e.g., as LEFT or RIGHT), and thus be able to control the input side of the automatic channel. Second, intentional processes might have an impact on how responses are coded (e.g., as LEFT or RIGHT), and thus be able to control the output side of the automatic channel. Third, intentional processes may even have a direct or indirect influence on the automatic translation process itself, or even have control over its effect on response selection and related processes. In fact, there is evidence for all three kinds of influence.

============= FIGURE 3 ==============

Stimulus Coding and Attention

Outside the lab, there are many ways to control even our strongest habits, with one of the best being distraction and ignoring: We avoid getting in touch and view with the stimuli we know to trigger inefficient, unwanted, or unacceptable behavior. But there are more subtle means also, such as ignoring a stimulus we are confronted with, or concentrating on a less critical stimulus attribute. Hence, the way stimuli affect our behavior strongly depends on whether we attend and how we perceive them, which is nicely demonstrated by studies on the impact of perception and attention on the Simon effect.

In the standard Simon task, only one stimulus appears at a time, and it is usually presented to the left or right of a central fixation mark. However, Simon effects can also be obtained with more complex visual displays, displays that require attentional selection of the stimulus. For instance, Grice, Boroughs, and Canham (1984) presented their subjects with two stimuli in each trial, one on either side, one being a to-be-discriminated response-signaling letter and the other a neutral distractor letter. Pronounced Simon effects (i.e., better performance if the target letter corresponded with the response it signaled) were obtained in this study, as well as in studies where target and distractor differed in color (Hommel, 1993b; Proctor & Lu, 1994) or meaning (O'Leary & Barber, 1993). Inasmuch as the Simon effect indicates automatic S-R translation, these findings show that it is not the stimulus information per se that is translated into response activation but the *attended* stimulus information only. Therefore, "automatic" translation processes critically depends on the intention to process a particular stimulus (Stoffer & Umiltà, 1997). This is also obvious from a study of Hommel (submitted b), where the stimulus displays looked like the one shown in panel A of Figure 4. The display always consisted of four differently colored objects, whose form signaled left and right responses. The actual target was cued by coloring a frame that surrounded the display, hence by presenting the color of the relevant stimulus. Although the stimulus display as such was more or less symmetrical, performance was much better if the cued target was on the same side as the response it required.

============= FIGURE 4 ==============

Another fine demonstration of the role attentional processes play in controlling automatic S-R translation was provided by Nicoletti and Umiltà (1989), who used a stimulus display as sketched in panel B of Figure 4. Subjects kept their eyes at a fixation mark to the left or right side of a row of six boxes, in which the stimulus appeared. Attention was to be focused on a small solid square located in between two boxes, with the particular location of the square varying randomly from trial to trial. Interestingly, performance did not depend on the side of the fixation mark or the stimulus, but on whether the stimulus appeared to the left or right side of the currently attended location, that is, it was best with correspondence between the location of the stimulus relative to the attended square and the location of the response.

Obviously, the very same stimulus condition can trigger very different responses depending on which part of the stimulus configuration is attended, which stimulus is searched for, and so forth. Given that in the described studies attention was induced and manipulated by means of instruction and, thus, was under voluntary control of the subjects, this means that automatic S-R translation as indicated by the Simon effect cannot be completely automatic and unconditional. Rather, intentional/attentional processes seem to implement a particular state or task set to code, analyze, and perceive the reaction stimuli in a particular way, and it is only this set that allows automatic translation processes to take place.

Response Coding and Intention

In addition to the input part of overlearned or compatible S-R couplings the output part also provides a means to control S-R translation and its effect on behavior. In fact, there is evidence that S-R compatibility effects strongly depend on the response part, on how a response is coded and interpreted, and on whether it is prepared in advance of the stimulus.

The role of response preparation has been investigated in the study of Hommel (1996). In one experiment, subjects responded during a whole block by pressing the same response key to the onset of a temporally unpredictable green square coming up on the left or right side. On very few occasions, a red square also appeared immediately after a response key was depressed. This signaled a further response with either the same key or, in a separate session, with the opposite key. That is, subjects were required to hold only one response in preparation in one condition, but two responses in the other—although the two responses were no real response alternatives. Interestingly, the two-key condition yielded a much more pronounced effect of (green) S-R correspondence than the one-key condition. This suggests that holding two responses in preparation results in, or even requires, much stronger spatial response coding than preparing only one response. Response coding, in turn, strongly affects automatic translation because, for obvious reasons, translating a left stimulus into a left response, say, only works if one of the responses is actually coded as left.

Further evidence that compatibility phenomena cannot only be affected, but are even determined by response coding, can be taken from the study of Hommel (1993c). In this study, subjects performed left and right keypresses in response to the pitch of a tone. Like in a typical Simon task, the tone was randomly presented through a left or right loudspeaker. In addition, each keypress flashed a light-emitting diode on the opposite side. In one group, the instruction referred to the response keys, hence subjects were asked to “press the left/right key in response to the low/high pitch”. A second group performed exactly the same task, but they were instructed to “flash the right/left light in response to the low/high pitch”. Given that flashing the right/left light was done by pressing the left/right key, one might not expect any impact of the instruction on a truly automatic translation process. Yet, the typical benefit of stimulus-key correspondence was only obtained under key instruction, whereas the light group showed exactly the opposite result (i.e., better performance with stimulus-light correspondence). Obviously, the light group had coded their responses in terms of light location and as these were always opposite to the keys, the effect was also the opposite.

In sum, processes of response coding and preparation are as effective as stimulus-coding processes in controlling both the degree and direction of “automatic” S-R translation. Given that response coding was a rather direct function of task instructions and the way these instructions were implemented, we see once more that automatic translation strongly depends on intentional processes.

Stimulus-Response Translation, Practice, and Task Set

Clearly, both stimulus and response coding processes play a decisive role for the occurrence of automatic translation. But there are even more direct influences on the effect of automatic translation processes, as well as on the likelihood and the time of their occurrence, just as indicated by the middle vertical arrow in Figure 3. For example, in the study of Hommel (1994), subjects performed a standard Simon task, except that the frequency of noncorresponding (incompatible) trials was varied from 20% to 80%. As a consequence, the location of the stimulus was no longer as uninformative as with 50% probability. In fact, frequency of noncorrespondence trials had a strong impact on the Simon effect: The effect sharply increased with low frequencies and was eliminated with the highest frequency. Obviously, then, (strategically?) using the information provided by a task-irrelevant stimulus attribute can overrule the effect of automatic S-R translation.

Interestingly, S-R contingencies and the associations and strategies they induce can even transfer to a different task. In the study of Proctor and Lu (in press), subjects performed a Simon task after receiving practice in a standard spatial compatibility task, with either a compatible mapping (left stimulus → left response, right stimulus → right response) or an incompatible mapping (left stimulus → right response, right stimulus → left response). The group practicing with the compatible mapping exhibited a normal Simon effect, with S-R correspondence yielding faster responses than noncorrespondence. However, the group practicing with the incompatible mapping showed the opposite pattern, that is, S-R noncorrespondence was now faster than correspondence. Hence, the association of stimulus and response locations strategically acquired in the practice task must have been involuntarily transferred to the Simon task, where the respective S-R associations counteracted the effect of S-R compatibility.

Strategies and task sets cannot only counteract, but also effectively eliminate automatic translation. An impressive demonstration of that phenomenon comes from Eimer and Schlaghecken (in press). As already mentioned, these authors presented their subjects with subliminal left- and right-pointing arrow-heads before the actual target stimulus, which again signaled a left-vs.-right keypress. If the target was also an arrowhead, the arrow primes produced LRPs indicative of automatic activation of the hand that corresponded to the prime’s direction. Of course, this is what one would expect from an automatic-translation approach to S-R compatibility. However, when the arrow targets were replaced by single-letter stimuli, the primes no longer produced an LRP. Therefore, if one attributes the effect of arrowhead primes on lateralized responses to automatic S-R translation, this kind of automaticity must strongly depend on whether and how a person intends to act to a given stimulus. This conclusion is also suggested by a study of Valle-Inclán and Redondo (1998), who measured LRPs in a Simon task with a trial-by-trial variation of the mapping between the relevant stimulus feature (i.e., color) and the response keys. If the mapping appeared before the stimulus, the stimulus elicited the usual LRP related to the spatially corresponding hand, but not if the stimulus preceded the mapping. Inasmuch as LRPs induced by stimulus location can be taken as an indicator of automatic S-R translation, this finding strongly suggests that automatic translation is tightly coupled to, and apparently even depends upon, the subject’s intention to act at the time of stimulus presentation. Although this does not always seem to be the case (Eimer, 1995), it at least demonstrates that under some circumstances task sets can have full control over automatic translation processes.

Conclusion

To sum up, we have seen that intentions by no means shield our response tendencies from being activated by environmental stimulation. Responses may become automatically activated by a stimulus if they were often paired with that stimulus in the past, and/or if they are compatible (i.e., share features) with it. Automatic S-R translation processes can be experimentally dissociated from intentional processes, they can be independently manipulated, and they can be shown to have different characteristics. Nevertheless, automatic translation processes are not completely independent from intentions. Indeed, intentions can affect automatic processing in many ways, for example by determining whether and how stimuli and responses are cognitively represented, or by defining and preparing intentional translation processes. That is, intentional processes do not so much compete with automatic processes, as assumed by Ach (1910) or later dual-route models, but rather set the stage for automatic processing to take place (Hommel, in press), which is more in line with the position of Lewin (1922b). If this is so, one may doubt whether there is such a thing like a pure intentional or pure automatic process at all. Intentional processes apparently install automatic processes and can therefore never have complete control over their results, whereas automatic processes depend on intentional preparation and are therefore always controlled. Thus, it seems that speaking of intentional and automatic processing is always relative and in a sense even wrong. However, to find out in which sense it is wrong requires a much better understanding of both how intentions are implemented into the human cognitive system, and how this implementation and its consequences are shaped by previous experience.

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Figure Captions

Figure 3: Illustration of possible influences of intentional preparation processes on automatic stimulus-response translation.

Figure 4: Schematic illustrations of the stimulus displays used in the studies of (A) Hommel (submitted a) and (B) Nicoletti and Umiltà (1989). See text for further explanations.