ELSEVIER

Acta Psychologica 89 (1995) 37-51

acta
psychologica

Conflict versus misguided search as explanation of S-R correspondence effects

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Received 9 August 1993; revised 20 December 1993; accepted 25 January 1994

Abstract

Two experiments investigated the impact of memory set size on effects of irrelevant spatial S-R correspondence. One vs. four stimuli were assigned to either hand, with random variation of the location of the target stimulus (Experiment 1) or of an accessory tone (Experiment 2). Correspondence effects decreased with increasing set size, thus disproving the buffer model of response selection suggested by Mewaldt, Connelly and Simon (1980). Instead, results are interpreted in terms of automatic stimulus-induced response activation that is subject to rapid decay.

1. Introduction

One of the most pertinent problems in both everyday life and experimental tasks is to select the most appropriate response from the huge number of behavioral alternatives humans have available. In a now classic work, Merkel (1885) reported that responses are initiated slower, as the set of equally probable stimulus-response alternatives increases. Later, these findings were replicated and extended by Hick (1952) and Hyman (1953), who also presented a formalization of the relationship between reaction time (RT) and the number of alternatives, known as the Hick-Hyman's Law. Accounts of this relationship (and of other response selection problems) can be roughly divided into two groups, according to whether response selection is conceptualized as a serial search through stimulus-response representations or as the outcome of a conflict between response codes that are activated in parallel.

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SSDI 0001-6918(94)00011-5

One of the first serial response selection models was presented by Hick himself (1952), who proposed that, in a choice reaction time task, the subject works through a chain of binary subdecisions of constant duration. In each step, the current stimulus is compared to the internal representation of one of the possible stimuli, until a match is found. As the number of necessary subdecisions increases with the number of stimulus–response alternatives, RT will be higher with a large than with a small stimulus–response set. As a parallel alternative to Hick's model, Berlyne (1957a,1957b), proposed an account of Hick–Hyman's Law in terms of conflicting response tendencies. He assumed that, throughout a trial or an experimental task, internal representations of the possible responses are activated to a certain degree, so that each response must be selected against a background of competing response tendencies. As competition is greater the more responses are possible (i.e., tendencies are aroused), RT rises with the size of the stimulus–response set.

The two response selection models presented by Hick and Berlyne differ in a number of ways: First, Hick's explanation is more in terms of stimulus codes than response codes, while Berlyne focuses explicitly on response codes. Second, Berlyne's approach permits simultaneous activation of response codes, while Hick's does not. Third, Hick's model is a static one, in that response selection is sketched as a rule-based search process of a fixed duration, while Berlyne's dynamic model conceptualizes response selection as the outcome of a conflict. The main goal of the present study was to investigate which of these concepts is more useful in explaining response selection problems that do not arise from the number of response alternatives, but from irrelevant spatial information.

Spatial information is known to greatly influence the selection of spatially defined responses. On the one hand, this has been demonstrated in tasks where spatial characteristics of the stimulus are relevant for response selection. For example, if subjects have to decide between pressing a left- or a right-hand key, responses are selected faster if signalled by spatially corresponding stimuli than by noncorresponding stimuli (Brebner et al., 1972). On the other hand, stimulus location affects response selection even if the response-relevant stimulus dimension is nonspatial. For example, the word LEFT or a green patch is responded to faster with a left-hand response when the word or the patch appears on the left than on the right side of some reference point (Hedge and Marsh, 1975; Simon and Rudell, 1967). That is, spatial correspondence of stimulus and response speeds up response selection, no matter whether stimulus location is relevant or irrelevant to the task.

The phenomenon of a correspondence effect despite irrelevant stimulus location, has become known as the *Simon effect*. It is very robust and can be obtained under a large number of stimulus, response, and task variations (for an overview see Simon, 1990; Umiltà and Nicoletti, 1990). It occurs even if the irrelevant spatial information is not provided by the stimulus itself (i.e., its location), but by an additional cue, such as a left- or right-hand tone accompanying a centrally presented visual stimulus (Simon et al., 1976). This variety is called the *accessory effect*. The finding of both correspondence effects, Simon effect and accessory effect, has stimulated not only diverse empirical activities, but also several theoretical accounts (e.g., Hasbroucq and Guiard, 1991; Michaels, 1988; Simon, 1969; Umiltà and Nicoletti, 1992; Wallace, 1971). Although these explanations show a considerable degree of overlap, they differ in important aspects. The aspect that will be investigated in this study concerns the way response selection is conceptualized. An account of correspondence effects is presented that describes response selection as a (possibly misguided) search through response buffers. Subsequently, empirical problems for this account are pointed out and a theoretical alternative in terms of a response code conflict is described. Predictions of both models are then tested against each other in two experiments.

1.1. A misguided search account

In their *buffer model*, Simon and colleagues (Mewaldt et al., 1980; Simon, 1990; Simon et al., 1976; see Arend and Wandmacher, 1987, and Hasbroucq et al., 1991, for very similar models) presented the maybe most explicit account of correspondence effects in terms of response selection. The model proposes that, for every possible response in a task, a response buffer is established, each containing a list of descriptions of those stimuli associated with the particular response. When a stimulus is presented and properly identified, the buffers are searched through for the description matching the stimulus in a serial, self-terminating scan. In a standard binary choice task, scanning starts in a randomly chosen buffer. However, with an irrelevant spatial cue the search begins with the buffer associated with the response that corresponds to the cue. That is, when the stimulus appears on the left side, the buffer associated with the left-hand response is scanned first. If then the task-relevant stimulus information (e.g., color) also calls for a left response, RT is fast because the correct buffer is scanned first. If, on the contrary, the task-relevant information calls for a right response, RT increases because the wrong buffer is scanned first. That is, interference effects caused by irrelevant spatial noncorrespondence of stimulus and response are attributed to a temporal delay due to a misguided search through response buffers. Obviously, the buffer model is a static one, thus standing in the tradition of Hick's (1952) conceptualization of response selection.

The empirical evidence presented in support of the buffer model comes from a study of Mewaldt et al. (1980). Subjects performed a binary choice task. One of the two possible responses was associated with a two-stimulus set (i.e., two stimuli mapped onto a response), the other with a four-stimulus set (i.e., four stimuli mapped onto a response). The visual stimulus appeared at a central location, but it was accompanied by a left-hand or a right-hand tone irrelevant to the task. So, the preconditions for a correspondence effect were clearly met. That is, the left response should be facilitated by a left-hand tone, but interfered with by a right-hand tone, while the reverse was expected for the right-hand response. However, the response buffers associated with the responses must be assumed to differ in size and, consequently, to cause different time delays when scanned: Misguided search through the larger buffer should produce a greater RT effect than through the small buffer. Suppose, for instance, the two and four stimuli were mapped onto the left- and right-hand response, respectively, and, in a given trial, a stimulus requiring the left response were accompanied by a right-hand tone. The tone would cause a search through the large buffer before the correct small buffer is scanned, so that the time delay should be rather large. If, on the other hand, a stimulus calling for a right response were accompanied by a left-hand tone, the time delay would be shorter, because the erroneously scanned buffer contains two items only. Thus, the prediction was that spatial tone–response correspondence should have a comparatively larger impact on the response associated with the two-stimulus set. In fact, the results were exactly as predicted: Responses associated with the two-stimulus set yielded a tone–response correspondence effect of 36 ms, but of only 17 ms for responses associated with the four-stimulus set.

1.2. Empirical problems for the misguided-search account

The buffer model of Simon and colleagues represents a plausible account of both the Simon effect and the accessory effect and it permits predictions, such as of the Mewaldt et al. findings, that could hardly be derived from many competing approaches with that clearness. However, there are several reasons to doubt the plausibility of this model, especially in its non-dynamic conceptualization of response selection.

First, there is psychophysiological evidence that, in noncorrespondence trials, the incorrect response can become activated earlier than the correct one. The preparation of wrong responses ipsilateral to irrelevant stimuli is indicated in lateralized readiness potentials (Leuthold and Sommer, 1993; Sommer et al., 1993) as well as in subthreshold motor activity in the wrong hand (Zachay, 1991). This strongly suggests that something more happens than mere scanning of response buffers. Responses seem to be quite active even before all the necessary items are scanned and their activity depends on spatial stimulus information. It would be obvious to associate correspondence effects with the presence or absence of activation of the wrong response or its central representation, instead of scanning operations of the proposed kind. Of course, this does not rule out the possibility that spatial cues do *also* function to bias buffer scanning, but the scanning notion would be superfluous in explaining correspondence effects.

Second, correspondence effects occur long after the response proper is selected. In one of my studies (Hommel, 1995), subjects were informed about the correct response in each trial, but were not allowed to respond immediately. Instead, after one second a Go or a No-go signal appeared on the left- or right-hand side. The result was a clear correspondence effect, that is, responses were faster when response location corresponded to Go signal location. This is difficult to reconcile with the buffer model, because the spatial information that is assumed to bias buffer scanning appeared one second after the response-relevant information, so that all the scanning operations should then have already been completed.

Third, apart from these obvious inconsistencies with the data, the buffer model is silent to several further findings regarding the Simon effect, and it is hard to see how it can be elaborated in order to account for them. As an example, it can be shown that, under certain conditions, the spatial correspondence between stimulus and the direction of wheel-rotation movements (Guiard, 1983) or between stimulus and an artificial visual action effect (Hommel, 1993a) becomes more important than correspondence between stimulus and effector location. Does this mean that response buffers are established with reference to action goals but not to effector location? If so, it would be difficult to explain that, in the same experiment, each of the relationships between stimulus and anatomical effector mapping, stimulus and effector location, and that between stimulus and artificial action effect contributes a correspondence effect of its own (Hommel, 1993a).

It is obvious that, all in all, the buffer model lacks empirical support. However, while the cited findings strongly suggest to watch out for a theoretical alternative, there are several arguments (or evasions, depending on the perspective) that can be raised in defense of the model. For example, the electrophysiological findings may be accounted for by assuming that the level of response activation simply reflects the current response bias of the information processing system. Perhaps, a search through a certain response buffer leads to or is accompanied by a priming of the corresponding response, which shows up in electrophysiological measures (see Sanders, 1990, for a similar interpretation of electrophysiological findings). This does not necessarily rule out the idea of buffer search, neither does it preclude an explanation of the Simon effect in such terms. The finding of Go signals affecting the initiation of already known responses however, seems to be a greater problem. But here, also, one could think of ad hoc explanations: Perhaps it is impossible for some reason to terminate response selection before the Go signal comes up. If so, the location of the Go signal may somehow override the existing response tendency and bias the eventual response buffer search.

Without any doubt, these arguments would be completely ad hoc and, even if valid and supported by independent evidence, would not turn the buffer model into a particularly powerful theoretical tool. However, a definite decision as to this model can certainly not be made on the basis of individual physiological or behavioral findings, but requires additional, convergent evidence.

1.3. A response code conflict account

The starting point for the following experiments was an alternative account of the findings of Mewaldt et al. (1980) that does not need a scanning notion and, consequently, is not confronted with the difficulties discussed above. This explanation rests on the idea that responses are represented by codes of their (perceivable) features (Greenwald, 1970; Hommel, 1993a; Kornblum et al., 1990; Prinz, 1990,1992; Wallace, 1971) and selected by activating the code(s) of one or more of the appropriate response's features. If irrelevant stimulus information is processed, all those responses are activated that share at least one feature with this stimulus, to a degree that depends on the amount of feature overlap. That is, (non)correspondence effects are attributed to a conflict between the response code that is activated automatically by stimulus location and the response code associated with the relevant stimulus information. The critical point here is that activation of response codes caused by irrelevant information (i.e., location) is assumed to decay over time, losing (inhibitory) impact on competing response codes (Hommel, 1993b,1994a).

The decay notion suggests that the temporal relationship between the coding of (and response activation by) irrelevant stimulus location and the coding of (and response activation by) the relevant stimulus information should be crucial for the magnitude of correspondence effects. With slower processing of the relevant information relative to location, the time available for the location-related code to decay is enhanced, hence the smaller correspondence effects. That is, every experimental manipulation that causes a delay or a slowing-down of the relevant stimulus feature without affecting the timepoint of location coding, is expected to decrease the size of Simon effects and accessory effects. This prediction has gained considerable empirical support from a number of findings, showing that the Simon effect decreases or even disappears when coding of the relevant information is delayed by stimulus eccentricity, low stimulus quality, low contrast, or gradual presentation over time (Hommel, 1993b), by low stimulus discriminability (Hommel, 1994a), by high stimulus-context similarity (Hommel, 1994b), or by inserting a secondary task (McCann and Johnston, 1992).

An application to the Mewaldt et al. (1980) results follows quite easily: As demonstrated by the set size main effect the authors obtained, two-stimulus sets permitted faster response activation than four-stimulus sets. This may be due to a strategy to first compare the stimulus with the small memory set and/or to the greater frequency of small-set members. (Since Mewaldt et al. found a comparable main effect of set size in an experiment that did not involve directional cues, it cannot be associated with biased scanning through response buffers.) That is, the speed of processing the relevant information depended on set size. Under the plausible assumption that the coding of accessory location (i.e., speed of processing irrelevant information) was not affected by set size, the temporal delay of stimulus processing to location coding should have been larger with large than with small sets. As the decay notion suggests decreasing correspondence effects with increasing delay, the Mewaldt et al. findings are exactly as expected.

A decay interpretation of an interaction between set size and correspondence rests on the assumption that response selection is the outcome of a conflict, but not of an orderly search. Thus, it is a dynamic explanation in the tradition of Berlyne (1957a,1957b). Directional cues are assumed to automatically activate response codes to a certain degree, but not to bias comparisons between the stimulus and stimulus templates. This latter difference with regard to the buffer model permits an empirical test between the decay interpretation and the buffer scanning interpretation suggested by Mewaldt et al. (1980). In the original study, the small set was assigned to one response and the large set to the other. In the present experiments, both responses were mapped onto stimulus sets of equal size, while set size was varied only between separate blocks. The buffer model predicts larger correspondence effects with large than with small sets: when the noncorresponding location cue directs the search to the wrong response buffer, more items must be scanned in vain with a large than with a small set. As correspondence effects are assumed to reflect misguided scanning, correspondence effects should increase with the size of the buffers that are erroneously scanned. The decay approach predicts the opposite: The delay of activating the correct response associated with the relevant stimulus information relative to activating the response corresponding to the irrelevant location cue is larger with large than with small stimulus sets. Because the location-correspondent response code decays over time, its decay is the more advanced – thus its impact on the correct response smaller – the larger the delay is. That is, small sets should produce greater correspondence effects than large sets.

2. Experiment 1

The first experiment combined the designs of the original Mewaldt et al. (1980) and the Hommel (1993b) study. On the one hand, small and large stimulus sets were used. In order to ensure a large main effect of set size, sets comprised one versus four items. On the other hand, sets of the same size were assigned to both hands, while set size varied blockwise. Further, the location cue was provided by the visual stimulus itself. That is, the target stimulus appeared randomly at a left or right location, but there was no accessory stimulus like in the Mewaldt et al. study.

2.1. Method

Subjects
Eighteen adults, 11 female and 7 male, were paid to participate in a single session lasting about 20 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

Apparatus and stimuli
Stimulus presentation and data acquisition was controlled by a Hewlett Packard Vectra QS20 computer, interfaced with an Eizo MD-B11 graphics adaptor and attached to an Eizo 9080i monitor. Responses were given by pressing the left or right shift key of the computer keyboard with the corresponding index finger. The fixation point (*) and the stimuli (♥, ♀, ☼ , §, %, &, ?, @, Ω, ϕ) were all taken from the standard character font and were white on a black background. From a viewing distance of approximately 60 cm, a character cell measured 0.3° in width and 0.4° in height. The fixation point appeared at the geometrical center of the screen, and the stimuli were centered 1.3° to its left or right.

Design and procedure
Every subject worked through a small-set block and a large-set block, with one or four stimuli mapped onto either response finger, respectively. The two non-overlapping memory sets were individually assembled for each subject by randomly

drawing from the ten possible stimuli without replacement. The order of the two set blocks was balanced over subjects. Each set block began with the presentation of the memory set and the mapping of the two set halves onto the two responses, without any time limit. Subjects were then given 32 familiarization trials, in which the members of the memory set including their response mapping remained visible on the lower part of the screen. In the small set block, these trials contained eight blocks of each of the four combinations of stimulus (or response) type and stimulus location (left or right) in random order; in a large set block, there were two replications of each combination of eight stimuli with two locations, instead. The experimental phase of each set block in which the memory set was no longer visible comprised 144 trials. In a small set block, these consisted of 36 replications of the four randomly ordered stimulus × stimulus location combinations; in a large set block, this corresponded to nine blocks of the 16 combinations.

In each trial, the sequence of events was as follows. After an intertrial interval of 2,000 ms, the fixation point was presented for 500 ms. Then, the stimulus appeared and stayed on until the end of the trial. The program waited until the response was given but not longer than 1,500 ms. Responses with the wrong key were counted as errors and responses with latencies above 1,500 ms were considered missing. In both cases, auditive error feedback was given, while the trial was recorded and then repeated at some random position in the remainder of the block.

2.2. Results

Missing trials accounted for less than 1% of the data and were not considered in the analyses. For each subject, mean reaction times (RTs) and proportions of errors (PEs) were computed as a function of set size (small vs. large), stimulus location (left vs. right), and response location (left vs. right).

A $2 \times 2 \times 2$-way analysis of variance (ANOVA) of the RTs revealed three effects. First, overall, responses were faster with a small than a large memory set (535 vs. 711 ms), $F(1,17) = 73.18$, $p < 0.001$. Second, an interaction of stimulus location and response location, $F(1,17) = 5.29$, $p < 0.05$, showed that left responses were faster to left than to right stimuli (618 vs. 628 ms), while right responses were faster to right than to left stimuli (615 vs. 631 ms). Third, this Simon effect was modified by a three-way interaction of stimulus location and response location with set size, $F(1,17) = 6.10$, $p < 0.05$. As shown in Table 1,

Table 1
Experiment 1: Mean RTs (ms) and error percentages (in parentheses) for small and large set size according to spatial S-R correspondence (C) and noncorrespondence (NC). Effect sizes (NC-C) for both set sizes in the rightmost column

Set size	C	NC	NC-C
Small	525 (3.2)	545 (3.8)	19
Large	708 (6.0)	714 (8.0)	6

small sets produced a larger correspondence effect than large sets. An additional analysis including the order of memory set blocks as a between-subjects factor confirmed that none of these effects did depend on whether the small or the large set block was run first.

An ANOVA of the PEs yielded only two marginally significant effects. First, small memory sets produced less errors than large ones (3.5% vs. 7.0%), $F(1,17) = 4.10$, $p < 0.06$. Second, correspondence produced less errors than noncorrespondence, $F(1,17) = 4.07$, $p < 0.06$, which was true for left (4.3% vs. 5.9%) and right responses (4.8% vs. 5.9%).

Since there was no three-way interaction in the PE data ($p > 0.27$), and, numerically, the correspondence effect was somewhat more pronounced in the large set condition, it was checked whether this might have been due to a speed–accuracy trade-off. For each subject and set size, correspondence effects were computed by subtracting RTs and PEs for conditions involving stimulus–response correspondence from RTs and PEs for noncorrespondence conditions. The correlations between these scores were clearly positive for small set size ($r = 0.26$) and for large set size ($r = 0.53$) as well. That is, the decrease in the RT correspondence effect with large set size cannot be attributed to a shift of this effect to error rates.

2.3. Discussion

The results are very clear in showing that the Simon effect decreases with increasing memory set size. This provides strong evidence against the buffer model of Simon and colleagues that would predict the opposite and, at the same time, it supports the notion that response activation decays over time. Such a conclusion is not limited by the absence of an interaction between Simon effect and set size in the error data, because, first, it was absent in the Mewaldt et al. (1980) study, too, and, on second, there was not the slightest indication of a compensating shift of the Simon effect from RTs to PEs with set size.

3. Experiment 2

In the preceding experiment the irrelevant location cue was provided by the target stimulus itself, which appeared at a left-hand or right-hand location. However, in the original Mewaldt et al. (1980) study, location cues were provided by an irrelevant tone sounding to the left or right of the subject. Although there is no obvious theoretical reason why this difference should be critical for the conclusions to be drawn from the results of Experiment 1, an empirical determination of this point would provide a firmer base for our conclusions. Consequently, Experiment 2 was conducted as a kind of replication of the preceding experiment, the only difference being that the irrelevant spatial information was provided by tones presented to the left or right of the central visual target stimulus.

3.1. Method

Subjects

Twenty adults, 11 female and 9 male, were paid to participate in a single session lasting about 20 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

Apparatus and stimuli

These were as in Experiment 1, with the following exceptions. The stimuli always appeared at the center of the screen, that is, at the same location as the fixation point. Simultaneously with the visual stimulus, a 100 ms 500 Hz sinus tone at 60 dB (measured from viewing distance) was presented through one of two loudspeakers, which were mounted on eye-height metal rods 52° left and right of screen center.

Design and procedure

Basically, the same design as in Experiment 1 was employed, the only exception being that it was the location of the accessory tone that varied and not that of the visual target stimulus. The only procedural change was that, in order to avoid masking of the central stimulus by the fixation point, the latter was presented for 100 ms, followed by a blank interval of 400 ms, before the stimulus came up.

3.2. Results

Missing trials ($< 1\%$) were excluded from analysis and the remaining data were treated as in Experiment 1. An ANOVA of the RTs produced the same three effects as before. First, responses were faster with a small than a large memory set (463 vs. 623 ms), $F(1,19) = 89.63$, $p < 0.001$. Second, left responses were faster to left than to right stimuli (538 vs. 548 ms), while right responses were faster to right than to left stimuli (535 vs. 548 ms), $F(1,19) = 12.91$, $p < 0.005$. Third, there was an interaction of stimulus location, response location, and set size, $F(1,19) = 4.76$, $p < 0.05$. Again, the correspondence effect was larger with small than with large memory sets (see Table 2). As in Experiment 1, none of these effects did depend on the order of memory set blocks.

An ANOVA of the PE data yielded a marginally significant effect of set size, $F(1,19) = 3.60$, $p < 0.08$, indicating less errors with small than with large sets (1.9%

Table 2

Experiment 2: Mean RTs (ms) and error percentages (in parentheses) for small and large set size according to spatial S–R correspondence (C) and noncorrespondence (NC). Effect sizes (NC–C) for both set sizes in the rightmost column

Set size	C	NC	NC–C
Small	453 (1.2)	472 (2.7)	18
Large	620 (2.6)	625 (4.3)	5

vs. 3.4%) and a highly significant correspondence effect, $F(1,19) = 19.07$, $p < 0.001$, showing that correspondence produced less errors than noncorrespondence in left (1.8% vs. 3.4%) and right responses (2.0% vs. 3.6%). The three-way interaction was far from significance ($p > 0.80$), but the correlations between correspondence effect scores for RTs and PEs were again positive for small ($r = 0.33$) and large set sizes ($r = 0.10$).

3.3. Discussion

The results were virtually identical to that of Experiment 1, in showing that the correspondence effect decreases with increasing set size. Obviously, this result cannot be attributed to the fact that in Experiment 1 the location cue was part of the stimulus. Even if accessory tones are employed like in the original study of Mewaldt et al. (1980), an underadditive relationship between correspondence and set size is obtained. This is further evidence against a buffer model of response selection, but is consistent with a conflict model that includes the notion of decaying response activation.

4. General discussion

Two experiments were conducted to investigate the impact of memory set size on the magnitude of effects of spatial correspondence between stimulus or accessory and response. Predictions were derived from the response buffer model suggested by Simon and colleagues (Mewaldt et al., 1980; Simon, 1990; Simon et al., 1976) and compared with predictions from a code decay approach proposed by Hommel (1993b,1994a). The results from the two experiments were very similar and permit the following conclusions:

First, large set size effects of comparable magnitude were obtained in both experiments (176 vs. 160 ms in Experiment 1 and 2, respectively). This suggests that set size effects are rather independent of the kind and modality of location cue, that is, of whether location cues are provided by the visual target stimulus itself or an irrelevant auditory distractor. Under the assumption that location cues affect response selection processes, such a result pattern is consistent with the hypothesis that memory set size affects a stage different from response selection (Sternberg, 1969).

Second, within a task, set size determines the size of correspondence effects. At first sight, this suggests that both factors affect the same processing stage – at least according to the additive factor method (Sternberg, 1969) – thus contradicting the foregoing conclusion. However, as Sanders (1980,1990) has pointed out repeatedly, the additive factor logic may not work with multi-attribute stimuli consisting of relevant as well as irrelevant (but effective) features. If we merely assume that responses can be activated by different stimulus attributes at different points in time (e.g., Miller, 1982,1988), there is no reason to conclude from a statistical interaction that the factors affected the same stage. Location cues may activate ipsilateral responses and their activation may decay to a degree that depends on how fast the other attributes are processed (Hommel, 1993b). This again may be influenced by a specific experimental manipulation, such as set size variation.

Third, the statistical interaction of set size and correspondence was clearly underadditive, instead of overadditive. Thus, the predictions from the response buffer model proposed by Simon and colleagues failed and their model must be rejected. In contrast, the results are consistent with predictions derived from the decay approach presented and extensively tested by Hommel (1993b,1994a,1994b). Originally, the decay hypothesis was described without any reference to response selection. This was because the first experiments presented in its support did not provide convincing evidence to rule out the idea that correspondence effects may be ascribed to stimulus identification, as has been argued only recently (Hasbroucq and Guiard, 1991; Stoffels et al., 1989). However, stimulus-related explanations have been shown to be both internally inconsistent (O'Leary et al., 1994) and empirically incorrect (Hommel, 1995; Leuthold and Sommer, 1993; Sommer et al., 1993; Zachay, 1991). The present results provide further evidence against a stimulus-related account. Logically, the matching of a stimulus against a memory set presupposes that it is identified to some degree and there is, in fact, empirical evidence that it is (e.g., Eriksen et al., 1986; Sternberg, 1967). So, the entire process that stimulus-centered accounts propose to be affected by location cues should have ended before the set size-dependent comparison process starts. If so, it is hard to see how set size can modify correspondence effects. Therefore, even though the decay principle, logically, can be combined with both identification-related and response selection-related accounts, a response-selection-plus-decay approach to correspondence effects seems to be the most promising.

Fourth, the result pattern for Experiment 1 and 2 was very similar, which was true for the size of correspondence effects and for the amount of decrease caused by the set size manipulation (see rightmost columns in Table 1 and 2). This implies that the Simon effect and the accessory effect do rest on identical mechanisms and that integrality of relevant and irrelevant stimulus attribute does not play a major role. The absence of integrality effects poses a problem for attentional models that assume that an attentional shift onto the target stimulus is responsible for correspondence effects (Stoffer, 1991; Umiltà and Nicoletti, 1992). In Experiment 2, the target stimulus always appeared at the center, so that no attentional shifting was necessary. Nevertheless, a full-blown correspondence effect occurred. Even the idea that tones may attract attention rapidly and in an automatic fashion (Posner et al., 1976) is of no help for these approaches, because stimuli are thought to be spatially coded relative to the current focus of attention: if attention were automatically attracted to a left tone first, a central visual stimulus would be coded as right, so that correspondence effects should be inverted. This is, of course, not consistent with the data.

Finally, and at a more general level, the present findings together with the similar empirical demonstrations of decay-like effects (Hommel, 1993b, 1994a,b, 1995; McCann and Johnston, 1992) and the electrophysiological evidence (Leuthold and Sommer, 1993; Sommer et al., 1993; Zachay, 1991) strongly suggest a dynamic explanation of spatial S–R correspondence effects in the tradition of Berlyne (1957a,1957b), rather than an explanation in terms of search times or other more or less fixed time delays. While the present study focused on the buffer model of the Simon effect, it should be noted that, strictly speaking, the claim for dynamic properties is insufficiently satisfied by most of the alternative S–R compatibility models, too (see Umiltà and Liotti, 1987, for an exception). However, these models differ as to the ease with which dynamic properties can be integrated:

For example, the Dimensional Overlap model of Kornblum et al. (1990) proposes that an irrelevant spatial stimulus feature automatically activates a spatially corresponding response. If this response is incorrect, it will be deactivated and the correct one will be retrieved. While the current version of this model can hardly account for a dependency of compatibility effects on stimulus features or memory set size, it would be easy to do so by adding the assumption that, if not immediately executed, automatically activated responses fade away over time.

Many more difficulties arise from the available findings for an ecological approach to compatibility (Michaels, 1988). According to this approach, compatibility effects reflect the perception of affordances in the sense of Gibson (1979), hence of possible actions in a situation. That is, the Simon effect would occur because, under noncorrespondence, the irrelevant stimulus location affords a different action than the relevant stimulus feature really requires. However, it is very difficult to understand why the affordance a stimulus location provides should depend on the size of the memory set or on other stimulus features affecting the temporal relationship between processing the relevant and the irrelevant feature. While it is plausible to assume, as the decay account does, that the state of a representational code (perhaps representing a possible action) varies over time, the affordance itself (i.e., the actor-related properties of the external event) should remain the same, at least as long as the situation or the actor's skills are not radically changed. Thus, an account of the present findings exclusively in terms of affordances does not seem very promising.

So, on the one hand, the results of the present study do certainly not rule out all kinds of alternative to the proposed response code conflict approach. On the other hand, they do require more or less considerable modifications of most current S–R compatibility approaches. That is, no matter whether one prefers the proposed account over a modified alternative or not, some kind of theoretical "dynamification" seems indispensable.

In conclusion, then, effects of irrelevant spatial stimulus–response correspondence, such as the Simon effect and the accessory effect, most likely arise from problems with response selection. This again is better conceptualized as a dynamic process resulting from conflicts between competing responses (or response-related codes), rather than a search through response buffers. Spatially defined responses (or their codes) seem to be activated automatically by location cues, but this location-induced response activation decays over time, thus losing impact on response selection.

Acknowledgements

I wish to thank Irmgard Hagen, Yvonne Lippa, and Albrecht Schnabel for collecting the data; Heidi John for checking and improving the English; as well as James Cauraugh and an anonymous reviewer for helpful comments and suggestions.

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