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Visual attention and manual response selection: Distinct mechanisms operating on the same codes

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In four experiments, participants made a speeded manual response to a tone and concurrently selected a cued visual target from a masked display for later unspeeded report. In contrast to a previous study of H. Pashler (1991), systematic interactions between the two tasks were obtained. First, accuracy in both tasks decreased with decreasing stimulus (tone-display)–onset asynchrony (SOA)—presumably due to a conflict between stimulus and response coding. Second, spatial correspondence between manual response and visual target produced better performance in the visual task and, with short SOAs, in the tone task, too—presumably due to the overlap of the spatial codes used by stimulus- and response-selection processes. Third, manual responding slowed down with increasing SOA—reflecting either a functional bottleneck or strategic queuing of target selection and response selection. Results suggest that visual stimulus selection and manual response selection are distinct mechanisms that operate on common representations.

The present paper deals with the relationship and possible interactions between two human control processes, one concerned with the selection of environmental stimulus information and the other with the voluntary selection of

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action. The first one, commonly called "attention", has been thoroughly investigated for decades in experimental psychology and, more recently, also in the neurosciences (for recent overviews, see Allport, 1983; Desimone & Duncan, 1995; Posner & Petersen, 1990). Most research in this area, the present work included, has been concentrated on visual attention, hence, the selection of visual stimuli or objects. Although many questions concerning the details of attentional selection are still unsettled (Allport, 1993), most researchers agree in that visual attention is in some sense capacity-limited, dealing with only one object (or few objects) at a time. In the process of selecting a given visual object, spatial stimulus information seems to play a major role, presumably because object features are cross-linked and integrated by referencing their common location in space (e.g., LaBerge & Brown, 1989; Schneider, 1999; Treisman, 1988; Van der Heijden, 1992; Wolfe, 1994).

The second control process of interest, commonly called "response selection", is assumed to be invoked whenever people are choosing among several possible actions. The response selection mechanism seems to share some characteristics with visual attention. As with stimulus selection, response-selection processes are believed to be strictly limited in capacity, dealing with only one response at a time (for recent overviews, see Pashler, 1993, 1994). Furthermore, studies on phenomena of stimulus–response compatibly (for a recent overview, see Hommel & Prinz, 1997) have repeatedly shown evidence of strong, spontaneous interactions between spatial stimulus and response codes, suggesting that spatial information plays an important role not only in stimulus selection, but in action control as well (e.g., Hommel, 1993a; Proctor, Reeve, & Van Zandt, 1992; Wallace, 1971).

How are visual attention and response selection, or the processes subserving them, related to one another? Despite some obvious similarities and some arguments for a more integrated view (Allport, 1993; Deubel, Schneider, & Paprotta, 1998; Rizzolatti, Riggio, & Sheliga, 1994; Schneider, 1995), mechanisms of stimulus and response selection have been traditionally treated as separate and independent—and, in fact, it may not seem obvious why it should be otherwise. Support for the traditional (although usually implicit) independence assumption comes from a study of Pashler (1991), the first one that tackled this issue directly. In Experiment 1 of that study, participants were presented with a visual attention task while performing a manual binary-choice task (see Figure 1 for our own, somewhat simplified, design version). The manual task required a speeded left or right keypress response (R1) to the pitch of a tone (S1). In the visual attention task, a brief masked letter array was presented. One of the letters was cued as target (S2) that was to be reported at leisure (R2) after the manual response. The stimulus–onset asynchrony (SOA) between tone and visual array and, hence, the temporal overlap of the two tasks, varied randomly between 50, 150, and 650 ms. Pashler reasoned that if both manual response (R1) selection and visual stimulus (S2) selection would require the same

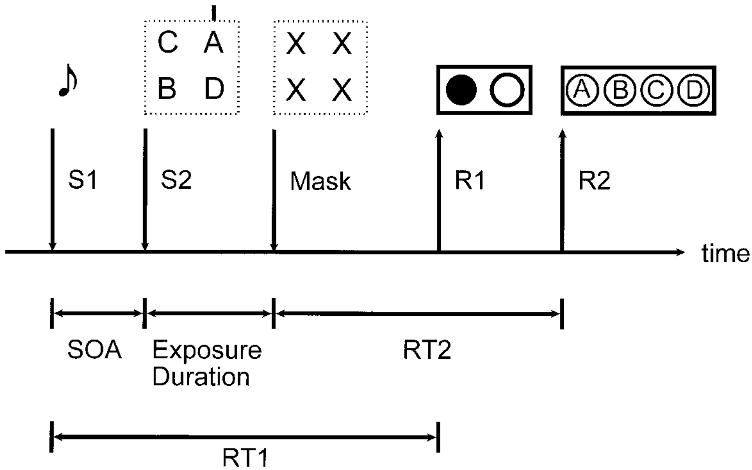

Figure 1. A schematic illustration of the procedure in Experiment 1. Task 1 requires a speeded left–right keypressing response to the pitch of a tone. Task 2 requires an unspeeded judgement of the marked target of a brief, masked four-letter display.

capacity-limited mechanism, then visual stimulus selection should suffer the more the greater the temporal overlap with manual response selection. Hence, the accuracy of S2 report should get worse the shorter the SOA. However, the results did not show any dependence of report accuracy on SOA, which led Pashler to conclude that visual attention and manual response selection do not rely on the same mechanism but are independent.

In our view, this conclusion might be premature for two reasons. The first reason has to do with Pashler's (1991) emphasis on SOA main effects as an indicator of interdependence between stimulus and response selection. Focusing on main effects makes sense from a bottleneck view, hence if we assume that interdependence necessarily shows up as a non-specific queueing of selection processes. However, interdependence may also produce specific interactions between stimulus and response selection, interactions that do not need to express themselves in SOA main effects. As already mentioned, both the selection of visual stimuli and of manual responses can be assumed to rely and operate on spatial representations. If one adds the assumption of a structural overlap between spatial stimulus and response codes (Hommel, 1997; Prinz, 1990) and/or the processes operating on them (Duncan, 1996; Rizzolatti et al., 1994; Schneider, 1995), one might expect rather specific patterns of spatially mediated interactions between stimulus and response selection. If, for instance, a left-hand keypress response is selected in the manual task, this might facilitate shifting attention to, or selecting, a left-side target stimulus in the visual task. As a consequence, one would expect spatial correspondence effects between (manual-)response location and (visual-)target location. Although such a correspondence effect might vary in size with SOA, thus producing a correspondence-by-SOA interaction, it would not yield an SOA main effect.

A second reason for us to hesitate accepting Pashler's (1991) negative conclusion is that it is based on investigating only three particular levels of SOA. If both tasks were processing in parallel, these values may not have produced (sufficient) temporal overlap of stimulus-selection processes in task 2 and response-selection processes in task 1 (cf., Hommel, 1993b). Moreover, both particular SOA values and the range of SOA levels have been shown to affect the strategies subjects employ under dual-task conditions, especially with combinations of an easy, speeded manual-choice task and a difficult, unspeeded visual-attention task (De Jong & Sweet, 1994). Thus, it may be that choosing other SOAs increases the temporal overlap of selection processes and/or induces different strategies in ways that do reveal interactions between stimulus and response selection.

In summary, we feel that Pashler's (1991) evidence for claiming independence of visual attention and response selection is inconclusive and possibly premature. In the present Experiments 1 and 2 we tested whether focusing on non-specific queueing effects in the original study might have concealed the view on specific interactions between stimulus- and response-selection processes. To do so, we replicated Pashler's first experiment and considered in our analyses not only effects of SOA, but also those of the spatial correspondence between R1, the manual response, and S2, the to-be-selected visual target stimulus. In Experiments 3 and 4 we investigated the role of temporal overlap of stimulus and response selection by using SOAs between 200 and 400 ms, a range that might be expected to increase overlap.

EXPERIMENT 1

Experiment 1 had two aims. First, we wished to replicate the most important finding of Pashler (1991, Exp. 1) by using a slightly simplified search task (i.e., four rather than eight letters, see Figure 1), but the same levels of SOA. In the visual attention task, Pashler found no effect of SOA, although he did find one in the manual task, where RTs decreased significantly from 650 to 150 ms SOA. This latter effect was not interpreted as resulting from temporal overlap of stimulus and response selection, but rather as a kind of warning effect—an issue to be treated in more detail in Experiment 4 and in the General Discussion. More relevant for the moment, however, is the question of whether the theoretically important null effect of SOA on the attention task can be reproduced.

Second, we did not only look for main effects of SOA, but also included analyses of the impact of spatial correspondence between visual target and manual response. If our previously mentioned considerations concerning specific interactions between spatial stimulus and response selection were correct, one would expect target–response correspondence to affect performance, whether a main effect of SOA occurs or not.

Method

Participants. Twenty-four adults were paid to participate in single sessions of about 50 min. They reported having normal or corrected-to-normal vision and audition, and were not familiar with the purpose of the experiment.

Apparatus and stimuli. The experiment was controlled by a Hewlett Packard Vectra QS20 computer, attached to an Eizo 9070S monitor via an Eizo MD-B11 graphics adaptor for stimulus presentation, and interfaced with a D/A card (Data Translation 2821) for auditory output. Tone judgements in the manual task were given by pressing the left or right of two microswitches mounted side by side on a slightly ascending wooden plate. Letter responses in the visual-attention task were given by pressing one of four horizontally arranged keys of the computer keyboard (function keys F1–F4, accordingly labelled as *A*, *B*, *C*, and *D*). Each participant operated the microswitches with the index and middle finger of the right hand and the computer keys with four fingers of the left hand.

Auditory stimuli (S1) were sinusoidal tones of 200 and 800 Hz. Each tone was presented simultaneously through two loudspeakers located about 50° left and right of the median plane. Visual stimuli were all taken from the standard text mode font and were presented in white on a black screen. A plus sign served as fixation cross, a vertical line as marker, the uppercase letters *A*, *B*, *C*, and *D* as stimuli for the visual task (S2), and four *X*s as mask. From a viewing distance of about 60 cm, each letter measured 0.3° in width and 0.4° in height. The fixation cross always appeared at screen centre. The four stimulus letters, as well as the four *X*s replacing them, were centred at the four stimulus positions 0.6° to the left and right and 0.4° above and below screen centre. The target was indicated by the bar marker appearing 0.3° (edge-to-edge) above the (upper) target or below the (lower) targe (see Figure 1).

Design. The experiment consisted of five blocks of 96 randomly ordered trials each, preceded by 40 randomly determined practice trials. The trials in each block resulted from the possible combinations of two tone stimuli or responses (left vs right key), three tone-letter SOAs (50, 150, or 650 ms), four letter targets (A, B, C, or D), two vertical target locations (upper vs lower row), and two horizontal target locations (left vs right).

Procedure. The verbal instruction stressed that tone responses should be speeded (within a reasonable accuracy range), whereas letter responses were to be given at leisure. Following an intertrial interval of 1300 ms, each trial began with the presentation of the fixation mark for 1000 ms and a further blank interval of 500 ms. The tone was then presented for 100 ms and the letter display appeared at a variable time after tone onset (50, 150, or 650 ms, depending on the SOA, see Figure 1). Each letter display consisted of the four letters *A*, *B*, *C*, and *D*, distributed across the four stimulus positions, with the target indicated by the bar marker. The identity and the location of the target letter depended on the respective condition and were thus balanced across trials, whereas the locations of the remaining three nontarget letters were determined randomly in each trial. After a variable exposure duration (see later), the marker was deleted and the reaction stimuli were replaced by the mask, which stayed on until the letter response was given.

Following tone onset, the program waited 1000 ms for the tone response. In case of a missing or incorrect tone response, or with anticipations (RT < 150 ms), auditory error feedback was given. The respective trial was recorded and repeated at some random position in the remainder of the block. In order to discourage speeded letter responses, the program did not accept those responses earlier than 700 ms after mask onset. There was no upper temporal limit for letter responses.

Exposure duration of the visual display was set to 400 ms during practice trials and then reduced to 200 ms when the first block started. At the end of each block, the duration was individually adjusted according to the error rate in the letter task since the last adjustment: It was reduced by 42 ms (corresponding to three screen-refresh cycles) with an error rate below 20%, but increased by 42 ms with a rate above 30%. After each block, participants were given feedback about their average RT in the tone task and their accuracy in the letter task. On that occasion, they could pause as long as they wished.

Results

Trials with missing tone responses or anticipations accounted for 2.9% and 0.1% of the data, respectively, and were excluded from analyses. For each participant, mean RTs and proportions of (choice) error (PEs) in the manual task, and PEs for letter responses in the visual task were computed as a function of R1–S2 correspondence and SOA.

Tone task. An ANOVA of RTs revealed that reactions were quicker with the two shorter than the longest SOA (462, 461, and 481 ms, respectively), $F(2, 46) = 5.50, p < .01$. For choice errors all three effects were significant. The main effect of SOA, $F(2, 46) = 12.38$, $p < .001$, indicated a monotonous decrease of error rates with increasing SOA (5.7%, 4.4%, and 2.6%, respectively), and the correspondence effect, $F(1, 23) = 8.85, p < .01$, was due to less errors being made with correspondence (3.5%) as compared with

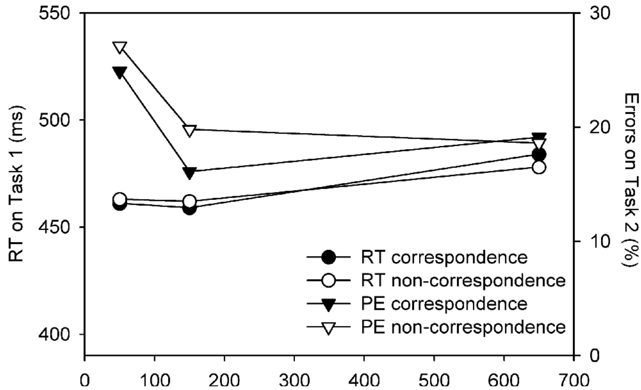

Figure 2. Experiment 1: Reaction times (RTs, in ms) on Task 1 and proportions of errors (PEs, in %) on Task 2 as a function of stimulus–onset asynchrony (SOA) and spatial compatibility between primary response and secondary target stimulus.

non-correspondence (4.9%). As indicated by the interaction, $F(2, 46) = 3.76$, $p < .05$, the correspondence effect was restricted to the two short SOAs (effect sizes: 2.2%, 1.9%, and 0.1%).

Letter task. The result pattern more or less mirrored the pattern of choice errors in the tone task. The SOA effect, $F(2, 46) = 11.50$, $p < .01$, reflected a substantial decrease of error rates from the shortest to the two longer SOAs (26.0%, 18.0%, and 18.9%, respectively), whereas the correspondence effect, $F(1, 23) = 7.05$, $p < .05$, was due to fewer errors with correspondence (20.0%) than non-correspondence (21.8%). Again, however, these two effects interacted, $F(2, 46) = 53.65$, $p < .05$, indicating that reliable correspondence effect were only obtained for the two shorter SOAs (see Figure 2).

Discussion

Experiment 1 yielded three relevant results. First, manual RTs did not increase with increasing task overlap, but there was a positive correlation between RTs and SOA instead (i.e., a decrease with increasing overlap). The finding of a positive relationship replicates the results of Pashler (1991) and will be discussed in more detail in Experiment 4 (along with the accompanying negative relationship in manual PEs). More important for now is the absence of a negative relationship, which indicates that manual response selection was more or less (if we ignore the effect in manual PEs for a moment) unimpaired by task overlap. Hence, if there was queuing of stimulus and response selection, it must have been the former that was delayed until the latter was completed. Indeed, the second important result is that, in contrast to Pashler (1991), we did obtain a main effect of SOA in the visual attention task. Following Pashler's reasoning this might indicate the queuing of (manual) response selection and (visual) stimulus selection. That is, stimulus selection might have had, or was scheduled, to await the completion of response selection. Third, however, the picture is complicated by substantial effects of spatial target–response correspondence on errors in either task, which points to some interaction between stimulus and response selection. In our view, a simple queuing story is insufficient to account for such an outcome pattern, for the following reasons.

One implication of our findings is that subjects seem to have some choice about when to start selecting the visual target. Obviously, correspondence effects on response selection as found in PEs presuppose that the visual target (or its marker) has already been located, which implies that stimulus selection must have at least started in some trials before the manual response was selected. According to the same reasoning, correspondence effects on the visual task indicate that other trials must have been associated with the reverse sequence, that is, target selection must have followed manual response selection. Moreover, correspondence affected manual errors at SOA levels that were not associated with any RT effect. This means that if in some trials target selection did start before the manual response was selected, this occurred without a RT cost. Put differently, working on target selection does not delay response selection. As this also implies the reverse—no delay of target selection by response selection—it raises two questions: First, why then were selection processes sequenced at all and, second, why did task overlap impair visual performance? To address these questions let us consider how and on what kinds of codes stimulus and response selection processes may operate.

A working model

One way to conceive this is illustrated in Figure 3A, where we slightly simplified matters by assuming that only two letters (A and B) appear in each visual display. Before a target is selected, so our explanation goes, its elements are read into and temporarily stored in some kind of working memory (cf., Schneider, 1999). As the target letter is not yet selected (for reasons discussed in Experiment 2), all the elements need to be spatially coded—otherwise later attempts to select the target letter according to a spatial criterion (i.e., whether or not it occupied the location indicated by the marker) would necessarily fail. This means that letter identities are bound to location codes, and vice versa, just as indicated on the left-hand part of Figure 3A. Responses are also spatially coded, which requires the binding of response identities to location codes (Stoet & Hommel, 1999; Wallace, 1971) as illustrated on the right-hand part of Figure 3A. Let us assume that R1 selection typically precedes S2 selection—as suggested by the asymmetry of SOA effects on manual RTs and visual PEs. If in the process of selecting a response one of the spatial codes is activated—the

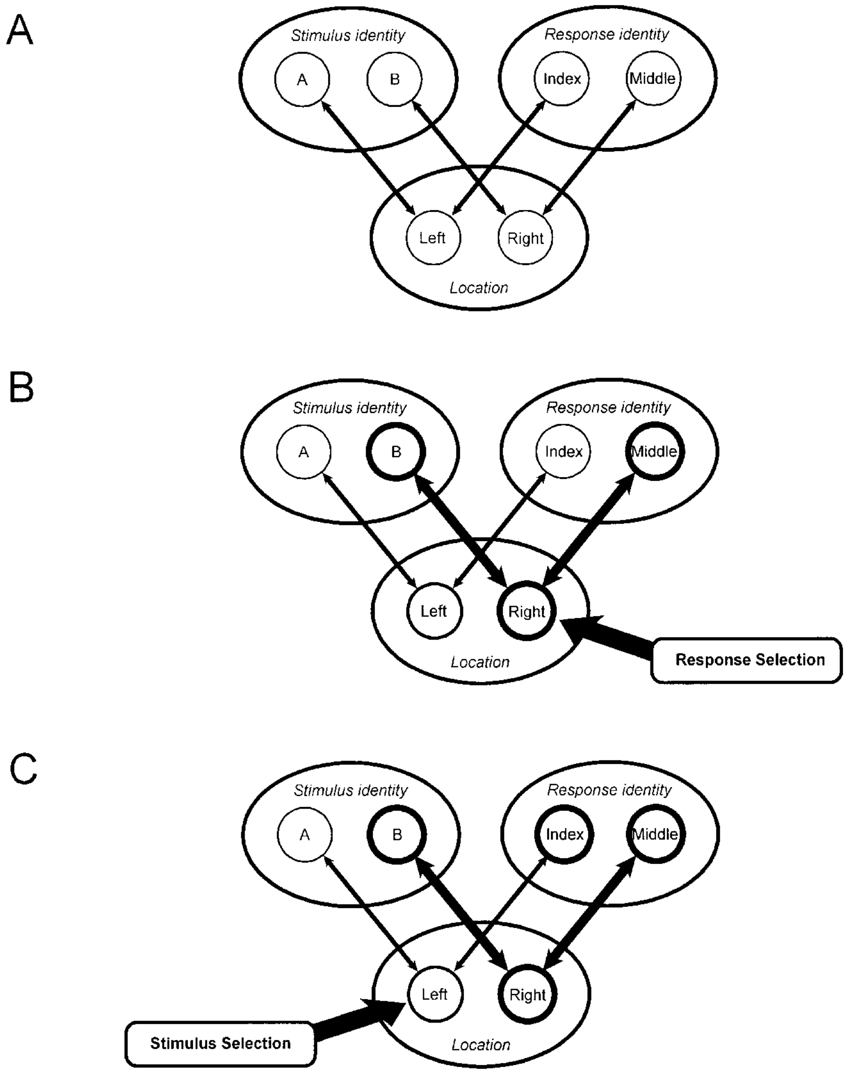

Figure 3. Simplified network of bindings between stimulus-identity (i.e., letter-related) codes and location codes on the one hand, and between response-identity (i.e., finger-related) codes and location codes on the other. The example is based on a two-letter display. Panel A shows the basic architecture, assuming that the letters A and B appear on a left and right location, respectively, and that a left and right response are operated by the index and middle finger of the right hand. Panel B illustrates how selecting a (right) response affects stimulus selection, while Panel C shows how selecting a (right) stimulus affects response selection.

RIGHT code, say—the stored code of the spatially corresponding target (here, the letter B) is also activated via the common link to the RIGHT code (see Figure 3B). Increased activation of a letter representation implies a higher probability of retrieving it from working memory when stimulus selection proper takes place, which supports target selection if this letter actually is the target but makes selection errors more likely if it is not (see the example for non-correspondence in Figure 3C). In other words, selecting a response primes the selection of (codes of) spatially corresponding stimuli.

This model can nicely account for our correspondence effects. As the stronger correspondence effects on the second than the first task suggest, response selection commonly preceded target selection, so that the outcome of the former influenced the latter according to the scenario in Figure 3B–C. However, as soon as the manual response was selected and executed there was no need to maintain the activation of the corresponding response-related codes any further and, in fact, there is evidence for a quick decay of response codes after use (Stoet & Hommel, 1999). Accordingly, correspondence effects only appeared when target selection immediately followed response selection but not at the longest SOA. Yet, even if targets are eventually selected only after response selection is completed, it may be possible to already prepare their selection to some degree by marking the target location (e.g., by activating the spatial code associated with the bar marker, which we have omitted in Figure 3). This would allow for a correspondence effect on manual RTs, which may not have appeared here for reasons addressed in Experiment 2, and on manual choice errors, which we did obtain in Experiment 1.

There are two possibilities to account for the SOA main effects we obtained in the visual task. One is to assume that selecting a response requires the same mechanism or resources needed for stimulus encoding. In a recent series of studies, Jolicoeur, Dell'Acqua, and colleagues (e.g., Jolicoeur & Dell'Acqua, 1998, 1999; for a recent summary, see Jolicoeur, Tombu, Oriet, & Stevanovski, in press) have provided strong evidence for interactions between stimulus encoding and response selection. They argue that processing a stimulus for later report requires consolidation of its code in working memory, a process that is assumed not to allow for concurrent response selection. According to this view, the SOA effects we obtained may reflect the effect of delayed consolidation: Selecting the manual response deferred consolidating the visual stimulus, the more so the greater the task overlap, so that information was lost with short SOA.

Alternatively, not the encoding of the visual items may have been deferred until (or, sometimes, carried out before) manual response selection but only the selection of the target from those encodings. That is, codes of all letter may have been bound to codes of their current location before, or concurrently with, manual response selection, but the actual target selection may have taken place only after response selection was completed. If so, the stored bindings may decay over time, so that increasing task overlap would lead to a loss of information about identity–location relationships. As stimulus selection relies on this information, the quality of its outcome will decrease with decreasing SOA.

Although our data will not allow a final conclusion, we find the latter scenario more plausible than the assumption of delayed consolidation. Consider visual performance with short SOAs: Even though error rates were increased with the shortest SOA, accuracy was relatively good at all SOAs and in no case approached chance level. Although this is partly a consequence of our adaptive presentation procedure, it is difficult to see how that reasonable performance was possible if any encoding had been suspended for several hundred milliseconds after the actual stimuli disappeared. Moreover, if consolidation is as time and resource consuming as the findings of Jolicoeur and colleagues suggest, it would seem odd to consolidate traces of the whole stimulus array before or even instead of selecting the target. Rather, it made more sense either to select the target on presentation—what does not seem to have happened—or to encode the items for later selection. This suggests that storing the whole display is somehow easier and/or goes quicker than selecting the target. Thus, our first guess regarding the impact of SOA on visual search in our design is that task overlap delays target selection, not visual encoding as such.[1]

This leaves open our first question, namely, why was temporal overlap of stimulus and response selection avoided at all? In our view, a possible, though tentative answer to this is suggested by recent observations of Müsseler and Hommel (1997a, b). They found that preparing a left or right keypress *impairs* both detection and identification of a feature-overlapping, masked stimulus, a pattern that Hommel and Müsseler (2002) were able to replicate with combinations of verbal actions and words. As proposed by Hommel, Müsseler, Aschersleben, and Prinz (in press) and Stoet and Hommel (1999), this may be due to that a feature code that is integrated into an action plan is, in a sense, temporarily "occupied" and thus less available for representing a stimulus possessing the same feature. Now, given that in our task the manual response and the

[1]Note that our preference, and the arguments supporting it, does not necessarily question the general assumption of Jolicoeur and colleagues that memory consolidation can constitute a real bottleneck. As Jolicoeur and Dell'Acqua (2000) have pointed out, consolidation costs may be much reduced if the display conditions are favourable, stimulus presentation is relatively long, and/or masking is not severe. Given our adaptive timing procedure, such conditions may have been met in our study. Moreover, the tasks employed by Pashler (1991) and us differ from the tasks showing clear demonstrations of consolidation costs. Whereas Jolicoeur and Dell'Acqua (1998, 1999) used tasks combining non-trivial demands on identification (identifying randomly presented, masked letters or symbols) with virtually none on spatial selection, our task had exactly opposite characteristics. Thus, all our subjects had to do when encoding and storing the visual stimulus was to bind known characters to new locations—a process that may not pose severe capacity problems on visual encoding and short-term storage.

visual target were spatially defined, there was always the possibility of feature overlap between response and visual target. To avoid any complication and confusion arising from that and, in particular, to prevent spatial codes needed for target selection from being occupied by manual action planning, any overlap between stimulus and response selection may have been circumvented. Hence, the sequencing of selection processes may have been a strategy to reduce crosstalk between stimulus- and response-feature codes in order to avoid selection errors. We get back to this consideration in Experiment 2.

In sum, Experiment 1 shows that Pashler's (1991, Exp. 1) main finding, the statistical independence between search performance and SOA, did not replicate. Instead, we find a substantial impairment in search performance with increasing task overlap. Moreover, search performance is better with spatial correspondence than non-correspondence between the search target and a concurrently performed manual response, also suggesting that stimulus and response selection processes are interdependent.

EXPERIMENT 2

Although we saw an effect of response–target correspondence in Experiment 1, it was asymmetric and only occurred in task 2. According to our explanation, this was because participants attempted to minimize interference of and from the manual task by merely encoding the visual display upon presentation and delaying target identification until the manual response was selected. Obviously, manual correspondence effects can only be produced by selecting the target, not by merely storing it, because it is the selection process that uses spatial codes to access and determine the target's identity via location-identity bindings (see Figure 3). As target selection followed response selection, it could not affect its outcome. One might object that at least the shorter SOAs in Experiment 1 (50 and 150 ms) should have allowed for selecting the target before the manual response. However, recall that these short SOAs were intermixed with a rather long one (650 ms), so that preparing to select the target before the response would not have paid for about one-third of the trials. Therefore, although participants could have often been able to select the target upon presentation, they may have been reluctant to do so. Instead, they may have favoured an all-purpose "late-selection" strategy they could apply to both short and long SOAs (for similar considerations, cf., De Jong & Sweet, 1994; Rogers & Monsell, 1995).

Admittedly, our story is post hoc, so that we conducted Experiment 2 to seek for independent evidence supporting it. One important and testable implication of our interpretation is that manual correspondence effects should show up if participants would only be given sufficient time to always select the visual target before the manual response. In Experiment 2 we restricted the range of possible SOAs to very small values only by replacing the 650 ms SOA of

Experiment 1 by one of 100 ms. That is, we used SOAs of 50, 100, and 150 ms, intervals that should provide participants with sufficient time to determine the visual target letter before starting to select their manual response. If so, and if participants would accept this offer, response selection would follow target selection and should therefore be affected by spatial target–response correspondence.

Method

Participants. Nineteen adults were paid to participate in single sessions. They fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, design, and procedure. These were as in Experiment 1, except that the three SOAs were 50, 100, and 150 ms, and that the error feedback was visual.

Results

Trials with missing tone responses (1.4%) and anticipations (0.1%) were excluded from analyses. The remaining data were treated as in Experiment 1.

Tone task. The RT analysis revealed two significant main effects (see Figure 4): RTs increased with SOA (443, 440, and 450 ms, respectively), $F(2, 36) = 3.93$, $p < .05$, and correspondence produced faster responses than

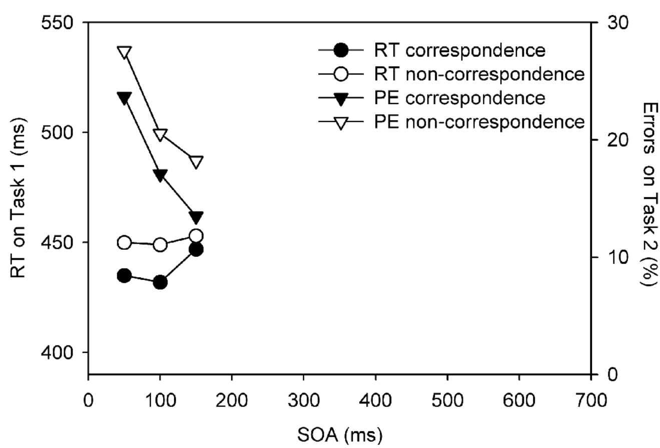

Figure 4. Experiment 2: Reaction times (RTs, in ms) on Task 1 and proportions of errors (PEs, in %) on Task 2 as a function of stimulus–onset asynchrony (SOA) and spatial compatibility between primary response and secondary target stimulus.

non-correspondence (438 vs 451 ms), $F(1, 18) = 19.34$, $p < .001$. The interaction approached the 10% level. The choice-error analysis yielded a significant main effect of correspondence, $F(2, 18) = 7.91$, $p < .05$, produced by smaller error rates with correspondence than non-correspondence (3.6% vs 5.2%).

Letter task. Both main effects were highly significant, SOA, $F(2, 36) = 17.53$, $p < .001$, and correspondence, $F(1, 18) = 27.82$, $p < .001$. As shown in Figure 4, error rates decreased with increasing SOA (25.6%, 18.8%, and 15.9%, respectively), and less errors were made with correspondence than with non-correspondence (18.1% vs 22.1%).

Discussion

The most important outcome of Experiment 2 is that, as expected, manual responses were clearly affected by spatial target–response correspondence. This strongly suggests that, in contrast to Experiment 1, the target was selected before manual response selection set in, or at least before it was completed. Selecting the target must have required, or been associated with, the activation of spatial codes representing its location and these codes must have affected the process of selecting the manual response. The interaction of correspondence and SOA fits well into this picture. Because with increasing SOA the likelihood increases that response selection begins before the visual target is identified, correspondence effects on manual responses become less and less likely.

Comparing Experiments 1 and 2 it is interesting to note that, in accordance with our speculation, exchanging just one SOA value (100 for 650 ms) was sufficient to change the whole outcome pattern, at least in the manual task. This is most obvious for the shortest SOA, which was associated with a substantial correspondence effect in Experiment 2 but not in Experiment 1. If the 50 ms SOA allowed for early target selection in Experiment 2 it should have done so in Experiment 1, too, which leads us to conclude that our participants were able to adopt rather different ways to coordinate their two sub-tasks in the two experiments. Hence, if the task context suggests that target selection is manageable before response selection, the visual display is analysed and the target is selected right after presentation. In contrast, the display is merely encoded if the task context suggests that target and response selection might often interfere with each other. That is, people seem to be able to configure their own cognitive system in order to meet external constraints on dual-task performance to quite a remarkable degree, a fact emphasized by De Jong and Sweet (1994) and Meyer and Kieras (1997).

Apart from its expected effect on manual responses, correspondence also affected letter-report performance. If we assume that correspondence effects in the search task reflect the impact of manual response selection on visual target selection, and if it is true that in Experiment 2 target selection took place before the manual response was selected, how can we account for the presence of such an effect? In our view, an effect of correspondence on target selection is surprising only if one assumes that selecting a stimulus object is a discrete, separable processing step of a fixed, short duration. Indeed, if the target letter would have been identified and selectively stored right after letter-display presentation, it would be difficult to see how this process could ever be affected by response-selection processes some 100 ms later. But assume target selection in the present context consisted in only priming the target letter for later report, hence increasing the activation level of the target-letter code to a greater extent than that of its competitors. To take the example from Figure 3, the target letter *A* may be selected by activating its identity code, as well as its associated location code (here: the *left* code), to a larger degree than the competing *B* code. Naturally, this would prime the corresponding manual response (here: the *index* code), thus producing manual correspondence effects of the kind observed in Experiment 2. As soon as the manual response is selected, including the activation of the response-related location code, activation of this latter code would spread to the associated letter-identity code. In the example, selecting the index-finger response would prime the letter code of *A*, whereas selecting the middle-finger response would prime the letter code of *B*. If priming through target selection and priming through response selection converge on the same identity code, the respective letter will be reported with a high likelihood, hence, accuracy will be high. However, if the target is primed by stimulus-selection processes, but one of its competitors is primed by response-selection processes, participants may sometimes erroneously report the competing letter, which impairs report performance. In other words, response–target correspondence can well affect target report even if target selection takes place before the manual response is selected.

The observation of a higher degree of interaction between the two tasks in the context of a rather small SOA range may suggest that these conditions tempted subjects to conjoin tasks, that is, to effectively transform the two tasks into one. Accordingly, one may doubt whether the outcome of Experiment 2 allows for conclusions that are applicable to standard dual-task situations. On the one hand, it is clear that blocking short SOAs did affect the way subjects scheduled stimulus- and response-related processes, thereby allowing more crosstalk between the tasks. On the other hand, though, there is no evidence for a strict temporal locking of processes across the two tasks. For instance, consider RTs and PEs for the two shortest SOAs in Figure 4. If the two tasks were really treated as one we would expect that manual response selection awaits stimulus processing in the visual task, which should delay RT with increasing SOA. Yet, there is not the slightest increase from 50 ms to 100 ms SOA, hence, no evidence of any grouping or synchronization of selection or other processes. For the same SOAs strong correspondence effects were observed in both tasks, which suggests that the underlying processes do not depend on task conjoining.

In sum, Experiment 2 shows that correspondence effects in manual responses, which were absent in Experiment 1, can be obtained if both the length and the range of tone-display SOAs is chosen to allow for selecting the visual target before manual response selection begins. This demonstrates that manual response selection can be affected by visual target selection in very much the same way as target selection is influenced by response selection, which provides further support for our assumption that stimulus and response selection are not entirely independent.

EXPERIMENT 3

Experiment 3 focused on a possible role of the degree of temporal overlap between stimulus and response selection. As the hitherto used SOA levels of 50, 150, and 650 ms do not fully cover the temporal range of possible interactions between the two selection processes, we chose to investigate SOAs of 200, 300, and 400 ms in Experiment 3, which in all other respects replicated Experiments 1 and 2. If Pashler's (1991) claim of independence between stimulus and response selection is correct, this modification should have no effects on the results, which amounts to predicting a null effect of SOA in either task. If, however, the degree of temporal overlap of the selection processes does play a critical role, an SOA main effect might show up in at least one of the two tasks.

Method

Participants. Twenty-four adults were paid to participate in single sessions. They fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, design, and procedure. These were as in Experiment 1, except that the three SOAs were 200, 300, and 400 ms.

Results

Anticipations (0.1%) and trials with missing tone responses (2.0%) were excluded from analyses. The remaining data were treated as in Experiment 1.

Tone task. In the RT analysis, only the main effect of SOA was significant, $F(2, 46) = 31.16$, $p < .001$, due to an increase of RTs with SOA (483, 501, and 530 ms, respectively). An SOA main effect was also obtained in the choice error analysis, $F(2, 46) = 5.55$, $p < .01$, but here performance was worse with the shortest than the longer SOAs (2.9%, 2.0%, and 2.4%, respectively).

Letter task. The main effect of correspondence was significant, $F(1, 23) = 7.47$, $p < .05$, as was the interaction of correspondence and SOA, $F(2, 46) =$

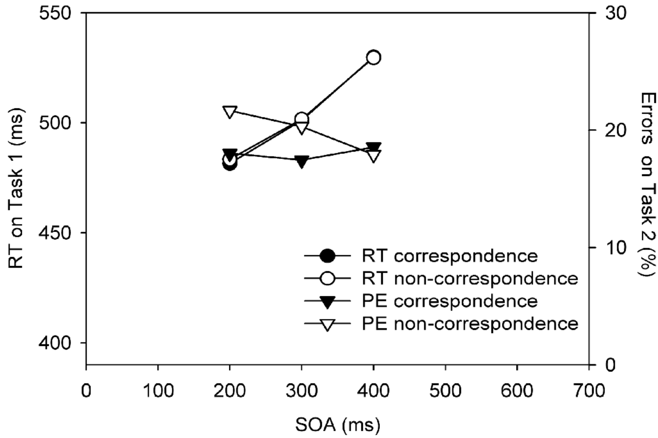

Figure 5. Experiment 3: Reaction times (RTs, in ms) on Task 1 and proportions of errors (PEs, in %) on Task 2 as a function of stimulus–onset asynchrony (SOA) and spatial compatibility between primary response and secondary target stimulus.

3.91, $p < .05$, whereas the SOA effect was not reliable ($p = .13$). As shown in Figure 5, substantial (and significant) correspondence effects were obtained with SOAs of 200 and 300 ms but not with 400 ms.

Discussion

First of all, we were able to replicate the correspondence effects on search performance for the two shorter SOAs. This completes the picture from Experiments 1 and 2 in indicating continuous decrease of correspondence effects with increasing SOA. According to the model sketched in Figure 3, such effects represent the impact of preceding response selection processes on target selection. And, indeed, this impact should get weaker as the delay of target selection to response selection gets longer.

Even more important in the present context, comparing the results of Experiments 1–3 reveals that our variation of the temporal overlap between manual response selection and visual stimulus processing led to a considerable change in the data pattern of Experiment 3. In particular, the effect of SOA on performance in the tone task became more pronounced with longer SOAs. Considering that increasing the SOA (within the range of manual RTs) is likely to increase the to-be-expected (but obviously avoided) temporal overlap of manual response selection and visual stimulus selection, this may be another indication of the strategic queuing of stimulus- and response-selection processes. However, there are three problems with this interpretation: (1) An easy one that can be rejected on grounds of the present data, (2) a not so easy one that we tested in Experiment 4, and (3) a crucial one that we will address in the General Discussion.

The easy problem is that the increase of RTs with SOA was accompanied by a decrease of choice errors, which might indicate a speed–accuracy tradeoff. Yet, there are two reasons to doubt that such a tradeoff was responsible for the SOA effect on RTs. One is, that choice errors in the tone task decreased with SOA in all four experiments of the present study—often to a larger extent than in Experiment 3, whatever SOA values were used and whether an SOA effect on RTs was obtained or not (see Figure 7). This mirrors the similar findings of Pashler (1991), who consistently observed negative correlations between choice errors and SOA across a number of task variations. Obviously, the error effect does not go with the RT effect but seems to be a standard byproduct of the basic task design used here (see General Discussion for some considerations on underlying causes). Another reason to doubt that our RT effect was due to a speed–accuracy tradeoff becomes evident if we compare the tone-task data from the two longest SOAs only (i.e., 300 and 400 ms). Here, RTs increased markedly from 501 to 530 ms, and so did the error rates (2.0% and 2.4%, respectively). Hence, a positive SOA effect on RTs can be obtained in the absence of a negative effect on errors, a finding that runs counter to a tradeoff account.

A perhaps more serious objection to interpret the SOA effect on RTs as a queuing effect has already been considered by Pashler (1991). The original idea of varying the SOA between the tone and the visual display was to manipulate the onset of stimulus-selection processes in the search task relative to response-selection processes in the tone task. If SOA has an effect, so the reasoning goes, this can be attributed to the varying degree of temporal overlap between stimulus- and response-related processes. However, note that this kind of manipulation confounds the variation of the onset of stimulus-directed processes with the variation of the onset of the visual stimulus itself. Therefore, we cannot be sure whether an effect of SOA really reflects characteristics of the attentional process we wish to index or only those of the attention-drawing visual stimuli. In fact, from studies on sensory facilitation we know that RT to a stimulus in one modality can be reduced by presenting a stimulus in another modality, even if this latter stimulus is irrelevant to the task (see Nickerson, 1973, for an overview). That is, responses in our tone task may have been quicker with short than with long SOAs not because visual stimulus processing hampered manual response selection with long SOAs, but because the mere presence of the visual stimulus display facilitated the manual response with short SOAs. As the validity of this interpretation cannot be evaluated on the basis of the present data, we conducted Experiment 4 to provide an empirical test.

EXPERIMENT 4

The aim of Experiment 4 was to find out whether the positive correlation between manual RT and SOA observed in Experiments 1–3 might have been due to sensory facilitation, hence, to an unspecific facilitation effect of the visual display. We tested the sensory-facilitation account by comparing the effect of the mere presentation of a letter-task display with the effect of requiring active processing of the display. We did that by using the same task and SOA range as in Experiment 3, but in addition to the *search blocks*, where participants again searched for a cued letter target, we also ran a *non-search block*, where the search display was presented but no search was to be performed. The predictions were straightforward. Clearly, we expected to replicate the increase of manual RT with SOA in the search block (apart from the correspondence effect on search performance). According to the sensory-facilitation hypothesis, the non-search block should give rise to the same positive relationship between RT and SOA—after all, the stimulus conditions were virtually identical in search and non-search blocks. In contrast, if visual-attentional processes were responsible for the increase of manual RT with SOA in Experiment 3, no such an effect should occur in the non-search block.

Method

Participants. Twenty adults were paid to participate in single sessions. They fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, design, and procedure. These were as in Experiment 3, with the following exceptions. One of the five experimental 96-trial blocks was replaced by a non-search block of about the same length (96 plus 9 additional catch trials, see later). During this block, the display conditions were basically the same as in the search blocks, including the presentation of the briefly masked four-letter displays at the three SOAs. However, the participants performed the tone task only but did not search for target letters. Accordingly, no target marker was presented and no letter was to be reported. In order to require the participants to monitor the visual events none the less, nine catch trials were randomly distributed across the block. In these catch trials a bright yellow frame appeared for 300 ms, which was to be responded to by pressing the space bar with 2000 ms after the tone response. Each frame appeared with one of nine randomly ordered frame–tone onset asynchronies, ranging from –200 ms (frame before tone) to 600 ms (frame after tone), in steps of 100 ms. The frame outline measured 3.3° × 3.6° with an edge-to-edge distance between frame and (area of) letter display of 0.3° horizontally and 0.4° vertically. The non-search block was run after the first, second, third, or fourth (i.e., last) search block. Its position was balanced across participants, so that each of the four possible positions was realized with two participants.

Results

Each participant responded correctly to all catch trials with no exception. Trials with missing tone responses (1.3%) and anticipations (0.02%) were excluded from analyses. The remaining data from the standard search blocks were treated as in Experiment 1. From non-search blocks, the data from catch trial were excluded and mean RTs and PEs for tone responses were computed as a function of SOA.

Tone task in search vs non-search blocks. A 2 × 3 (Task context × SOA) ANOVA was run on the RTs to tones from search and non-search blocks. Apart from a significant effect of SOA, $F(2, 38) = 9.05$, $p < .001$, responses were quicker in the non-search block than in search blocks (397 vs 497 ms), $F(1, 19) = 61.56$, $p < .001$. More important, the interaction was significant, $F(2, 38) = 16.67$, $p < .001$. As shown in Figure 6 and confirmed by separate analysis, this was due to that RT increased with SOA in the search blocks, but not in the non-search block. The errors analysis did not produce significant results. The SOA main effect approached the significance criterion ($p = .051$), but the underlying pattern was opposite to the RT pattern (5.3%, 3.6%, and 3.8% in search blocks, and 3.9%, 3.8%, and 2.8% in non-search blocks).

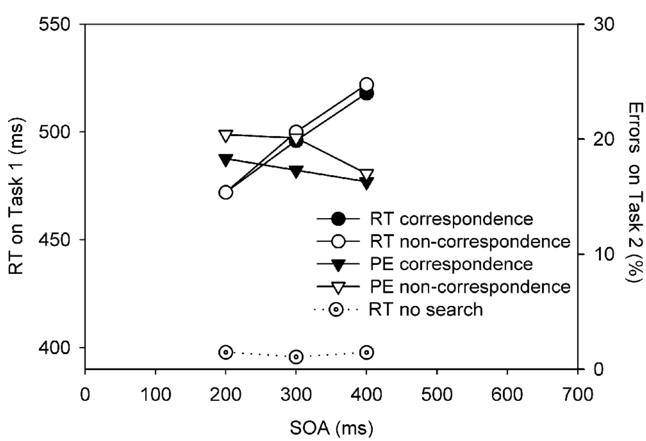

Figure 6. Experiment 4: Reaction times (RTs, in ms) for search blocks (straight lines) and non-search blocks (dotted line) on Task 1 and proportions of errors (PEs, in %) on Task 2 as a function of stimulus–onset asynchrony (SOA) and spatial compatibility between primary response and secondary target stimulus.

Tone task in search blocks. In the RT analysis (Correspondence × SOA), only the main effect of SOA was significant, $F(2, 38) = 16.92$, $p < .001$, reflecting an increase of RTs with SOA (472, 498, and 520 ms, respectively). An SOA main effect was also obtained in choice errors, $F(2, 38) = 6.65$, $p < .005$, again indicating that the shortest SOA was associated with an increased error rate (5.3%, 3.6%, and 3.8%). Interestingly, the main effect of correspondence was also significant, $F(1, 19) = 10.30$, $p < .005$, indicating less errors with correspondence (3.6%) than non-correspondence (4.9%), whereas the interaction missed the 5% level ($p = .072$).

Letter task. Both main effects were significant. The effect of SOA, $F(2, 38) = 7.74$, $p < .005$, indicated that errors decreased with increased SOA (19.3%, 18.7%, and 16.6%) and the effect of correspondence, $F(1, 19) = 7.53$, $p < .05$, showed that less errors were made with correspondence (17.3%) than with non-correspondence (19.2%).

Discussion

The results are clear-cut. In all relevant aspects the findings from Experiment 3 were replicated. In particular, when participants searched through the visual display their manual RT increased again as a function of SOA—in fact, the RT slopes in the two experiments are virtually identical. However, when the display was just presented with no search being required, RT was no longer positively correlated with SOA. This is strong evident against the idea that the SOA effects on manual performance in search blocks might reflect sensory facilitation by the mere presence of a visual stimulus. Obviously, the SOA effect is related to perceiving and processing a visual display, not just to watching it. Taken altogether, then, the present data allow us to reject both the speed–accuracy and the sensory-facilitation account of the effect of SOA on manual RT.

GENERAL DISCUSSION

Our goal was to investigate the relationship between visual attention and manual response selection, and to identify possible interactions of processes subserving the selection of visual objects and of manual responses. We did that by using Pashler's (1991) technique of pairing a speeded manual binary-choice task with an unspeeded attention-demanding letter-report task under varying degrees of temporal task overlap. Although Pashler found no indications for a dependence of letter-report performance on task overlap, we had two reasons to object his conclusion from this finding on the independence between visual attention and response selection. First, we argued that the interdependence between stimulus and response selection need not necessarily express itself as non-specific interference on secondary-task performance, but may produce specific effects of spatial correspondence between the manual response and the to-be-attended letter target. In fact, we were able to find such specific effects in each of our four experiments. Second, we pointed out that Pasher (1991) used only a limited set of SOAs, which may have concealed or prevented possible interactions of the critical selection processes. Indeed, we found an increase of dual-task costs under conditions that can be expected to increase temporal overlap of target processing and response selection. Summing up, the present findings do not support the assumption that visual attention and manual response selection are entirely independent, but rather suggest the existence of both non-specific and specific interactions, which we will now discuss in turn.

Non-specific interference between tasks

In all four experiments of this study, the accuracy of both manual choices and letter reports varied systematically as a function of SOA, that is, of the temporal overlap between the tasks. Interestingly, the two effect patterns are very similar, as is obvious from Figure 7. The error rates in the manual task

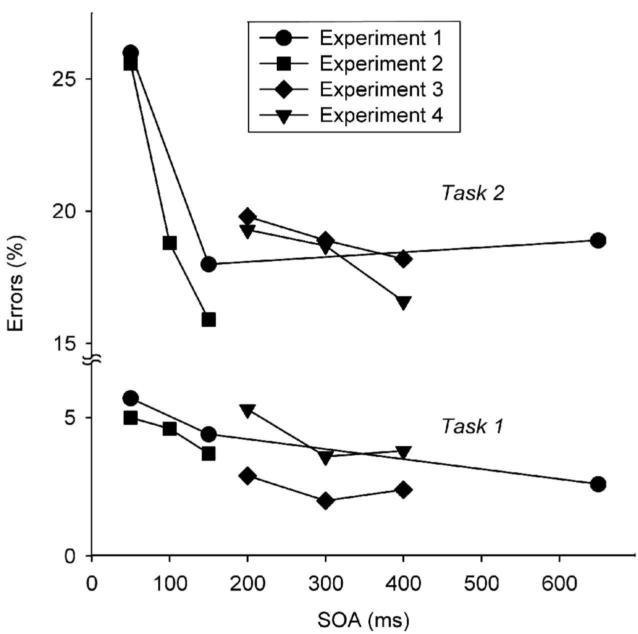

Figure 7. Overview of the proportions of choice errors made on Task 1 and search errors made on Task 2 of Experiments 1–4 as a function of stimulus–onset asynchrony (SOA).

consistently decreased with SOA in all four experiments and so did the error rates in the search task. The first part of this pattern, the SOA dependency of the manual errors, is consistent with the results of Pashler (1991), and other authors have reported similar findings. For instance, De Jong and Sweet (1994) and Pashler (1989) obtained SOA-dependent error rates in either task with combinations of speeded manual responses to auditory pitch and unspeeded reporting the highest digit in a briefly masked visual display. Apparently, then, presenting a tone and a visual search display in close succession impairs either task and the question is “why?”.

One possibility is that switching between stimulus modalities takes time (e.g., Cohen & Rist, 1992). If so, switching from primary- to secondary-task modality may not have been completed with short SOAs, which would have impaired the processing of the second stimulus. However, a modality-switching account would suggest that the SOA effect is only, or at least much more, observed in the secondary task, which is inconsistent with our findings. Moreover, recent findings suggest that attending to targets appearing in fact succession is easier, rather than more difficult, if they differ in modality (e.g., Duncan, Martens, & Ward, 1997).

Another possible account may assume that identifying a stimulus requires explicit preparation, as proposed by De Jong (1993; De Jong & Sweet, 1994). Again, one may object that this suggests error rates to increase at short SOAs for the second, but not the first task. However, De Jong and Sweet (1994) have provided evidence that subjects do not always prepare for the first task first (or most), especially if the second task involves attention-demanding visual discriminations. Thus, our subjects may have distributed their preparatory capacity across both tasks, or may have alternated between preparing for one and the other task, so that errors in either task could have been affected by SOA. However, according to such a preparation-strategy account blocking the very short SOAs in Experiment 2 should have led a greater emphasis on the visual task than in Experiment 1. Yet, visual error rates were comparable with 50 ms SOA and, if anything, errors in the auditory task were less frequent than in Experiment 1. In view of faster manual RTs in Experiment 2 than Experiment 1 this does not leave much support for a preparation account. Moreover, the fact that manual RTs were hardly affected at all by SOA, especially at very short SOAs, strongly suggests that processing the tone had not to await completion of visual processing. Thus, any account assuming strictly serial stimulus processing, such as that of De Jong and Sweet (1994), is difficult to apply to our findings.

This leaves us with our working model. We have suggested that in our task both auditory and visual stimuli are encoded upon presentation, but the eventual selection of the visual target is scheduled to either precede manual response selection (e.g., when SOAs are all short enough) or to wait until the manual response is selected. Accordingly, one problem for a delayed visual stimulus selection is the possible loss of stimulus information and, in particular, of information about letter–location relationships. As this kind of loss is likely to increase over time, increasing task overlap should lead to an increase in search errors, just as observed. Moreover, encoding the visual stimuli immediately on presentation increases the competition with codes of the auditory stimulus and, perhaps, of its assigned action. Consider, for instance, coding of the tone, the search-display items, and the manual response take place in the same capacity-limited coding system (i.e., working memory; as sketched in Figure 3), in which activating and maintaining a code or a code compound directly leads to a decrease of other codes' activation levels (cf., Schneider, 1999). If so, coding and maintaining the search items in this system would interfere with the coding of any other event, be it the tone or the manual response, and vice versa. Accordingly, the coding of stimuli (and, perhaps, responses) gets more difficult and error-prone the greater the temporal overlap of the two tasks, hence the SOA effects on even the auditory task.

A further, also non-specific interaction between the two tasks refers to the manual RTs and their increase as a monotonous function of SOA. We have argued that, although the errors do show an opposite tendency as the RTs, the particular result pattern does not suggest a speed–accuracy tradeoff. Moreover, the observation from Experiment 4 that the RT effect disappears if participants no longer search through the visual display, rules out Pashler's (1991) account in terms of sensory facilitation. Instead, it seems that participants were reluctant to schedule their selection processes in a way that would produce temporal processing overlap, possibly because overlap would have resulted in coding or selection conflicts of the sort demonstrated by Müsseler and Hommel (1997a; Hommel & Müsseler, 2002). This is apparent from the SOA main effects on RTs in Experiments 3 and 4, which suggest that response selection was sometimes delayed until the search display was presented (and encoded). Possibly, these cases reflect trials in which the processes preceding response selection took relatively long, so that temporal overlap of target and response selection was expected. Avoidance of temporal processing overlap is also suggested by the different manual correspondence-effect patterns in Experiments 1 and 2. When only short SOAs were used, as in Experiment 2, some indications for the preparation of target selection were obtained (i.e., the manual correspondence effect); yet, no evidence for target-related processing before response selection was found if a long SOA was included, as in Experiment 1. According to our interpretation, this is because target selection was immediately prepared (but not yet completed) only if and when no temporal overlap with response selection is to be expected—such as when the visual display always appeared before response selection was initiated. Here we assume that in performing one or more tasks, people are not bound to work through a fixed chain of cognitive processes, as assumed by stage models of information processing, but are able to flexibly tailor the temporal order of those processes to the task demands at hand (Meyer & Kieras, 1997). In our task, subjects employed this ability to keep stimulus and response selection separate. However, whether they did so by necessity or preference we are unable to tell—after all, avoiding concurrent selection does not mean that it cannot be done in principle. In cases of no code overlap and overlearned associations between the features of a given stimulus and response, it may well be that both can be selected at the same time. Thus, it still needs to be determined whether the bottleneck our findings point at is of functional or strategic nature.

Code sharing between stimulus and response selection

We consistently obtained effects of spatial correspondence between visual target and manual response, which demonstrates that stimulus and response selection can affect each other. However, these correspondence effects were asymmetric, with response selection always affecting stimulus selection, but stimulus selection affecting response selection only in Experiment 2. As already pointed out, the mere presence of this asymmetry suggests that correspondence effects do not reflect the *direct* interaction of concurrent selection processes but, rather, aftereffects of one selection process on the other due to the sharing of cognitive codes. According to our interpretation, the visual target was not determined on the basis of the sensory information presented on the screen, but selected from a transient (working) memory representation of the letter-display elements. Presumably, this selection took place during the interval between the manual response and the letter report, so that it was open to aftereffects of response selection. Even in Experiment 2, where there was some time to process the visual target before the manual response, target selection was only prepared but was not yet completed before the manual response was carried out—otherwise response–target correspondence could not have affected report accuracy of that short SOAs. From this follows that target selection should not be envisioned as a discrete act of transforming the status of an object from mere input to target once for all. Instead, selection may simply mean marking or priming (i.e., increasing the activation level of) the target representation for later use, as assumed, for instance, in the attentional models of Bundesen (1990) or Van der Heijden (1992). This marking or priming operation should greatly increase the chances of an item to affect later action (e.g., letter report), but it does not seem to shield the selected target from competition with other items as long as that action is not underway (Schneider, 1999). Interestingly, the same can be said of response selection: Even if, for instance, a left- or right-hand response is validly precued, so that it can be selected long before its execution is signaled, it is still affected by its spatial compatibility with the go signal, hence, sensitive to conflict with a competing response (Hommel, 1996).

A rough but plausible sketch of the how of specific interactions between stimulus and response selection has already been laid down in Figure 3. Basically, we assume that both stimulus and response representations are made up of identity-specific codes and location codes. For our argument it is not essential exactly how stimulus and response identity are represented—whether by single, integrated "integrated" codes, as our (in this respect too) simplified figure might suggest, or by more complex clusters of stimulus-feature codes, as claimed by Hommel (1998b), Kahneman, Treisman, and Gibbs (1992), and others. But it is important that these identity representations are temporarily associated with codes that refer to their (presumably allocentric-relative) location. Because both stimulus and response are thus spatially coded, their representations overlap (i.e., are shared) to a degree that depends on their spatial correspondence. Code overlap, however, is well known to produce compatibility effects (Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990) and, in a way, this is what we obtained.

In fact, the correspondence effect of target marking on response selection shows obvious parallels to the Simon effect (Simon & Rudell, 1967; see Lu & Proctor, 1995, for an overview), which refers to the finding that spatially defined responses are faster to spatially corresponding than non-corresponding stimuli, even if the location of that stimulus is not relevant. As in a Simon task, we found that the location of the target stimulus affected the selection of the manual response, even though this stimulus and this response, as well as their locations, did not depend on each other. It is true that in standard Simon tasks only a single stimulus is presented, not an array from which the target is to be selected. However, previous demonstrations of Simon effects with multiple-item displays (e.g., Grice, Boroughs, & Canham, 1984; Hommel, 1993c; Proctor & Lu, 1994) have already shown that this is not an essential task feature, so that the present observation of correspondence effects is not too surprising—if one only allows for crosstalk between the manual and the search task (or outcome conflict in the sense of Navon & Miller, 1987).

More surprising—and theoretically interesting—from a compatibility point of view are the "backward" correspondence effects of manual response selection on visual target selection. To our knowledge, this is the first demonstration of an action-induced biasing of visual search, although it is not the first observation of action effects on perception. Apart from the already mentioned studies of Müsseler and Hommel (1997a, b; Hommel & Müsseler, 2002), there is also evidence for backward effects under more standard dual-task conditions. Hommel (1998a) showed that in a dual-task design the congruence between a secondary-task colour–word response and a primary-task colour stimulus facilitates processing of the latter, hence, there is a colour-related backward compatibility effect of verbal response selection on a visual target identification. In the present experiment, compatibility referred to the location, not to the direction, meaning, or colour of the stimuli, and what was affected was (presumably) the selection, not the identification, of the target. Nevertheless, the evidence available so far does converge to indicate that code sharing between stimuli and responses not only affects response selection, as has been commonly assumed (e.g., Kornblum et al., 1990), but stimulus processing as well (Hommel, 1997; Hommel et al., in press; Müsseler & Hommel, 1997a; Prinz, 1990). That is, stimulus–response interactions can go either way.

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