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Reducing and Restoring Stimulus-Response Compatibility Effects by Decreasing the Discriminability of Location Words

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Abstract

In two experiments, we compared level of activation and temporal overlap accounts of compatibility effects in the Simon task by reducing the discriminability of spatial and non-spatial features of a target location word. Participants made keypress responses to the non-spatial or spatial feature of centrally-presented location words. The discriminability of the spatial feature of the word (Experiment 1), or of both the spatial and non-spatial feature (Experiment 2), was manipulated. When the spatial feature of the word was task-irrelevant, lowering the discriminability of this feature reduced the compatibility effect. The compatibility effect was restored when the discriminability of both the task-relevant and task-irrelevant features were reduced together. Results provide further evidence for the temporal overlap account of compatibility effects. Furthermore, compatibility effects when the spatial information was task-relevant and those when the spatial information was task-irrelevant were moderately correlated with each other, suggesting a common underlying mechanism in both versions.

Keywords

Simon effect; stimulus-response compatibility; temporal overlap; automatic activation

Responses to objects in the environment are faster and more accurate when the responses match features of those objects. For example, subjects are faster at responding to a left stimulus with a left response and a right stimulus with a right response than the reverse (Simon & Rudell, 1967). This preference for corresponding stimulus-response (S-R) mappings is broadly called the spatial S-R compatibility effect (Proctor & Vu, 2006). The compatibility effect is commonly viewed in terms of a dual-process model in which voluntary, goal oriented response activation competes with an environmentally, or exogenously, activated response that corresponds to features of the task stimulus (e.g., Kornblum, Hasbrouq, & Osman, 1990). Accordingly, to at least some degree, compatibility effects represent how much a feature of the environment automatically activates a response that conflicts with production of the correct, task-relevant response. Responses are slower and less accurate when these two activated responses are in conflict than when they both lead to the same response. A variety of stimulus features convey information that may lead to automatic response activation. In addition to the location of a stimulus, responses may be activated by conceptual information such as the spatial words

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“LEFT” and “RIGHT” or left and right pointing arrows (Lu & Proctor, 1994; Proctor & Wang, 1997; Weeks & Proctor, 1990). Therefore, it is of great interest to understand determinants of the timing and magnitude of automatic response activation and how this response activation may be modulated.

Fitts and Deininger (1954) were the first to formally describe the compatibility effect in which participants are faster at responding to a spatial feature of a stimulus when this feature and the response closely correspond to one another. Deininger and Fitts (1955) subsequently explained this result as an issue of S-R translation: Responses are slower when they do not match stimulus features than when they match because additional processing steps are required to translate the presented stimulus into a response. Within Kornblum et al.'s (1990) taxonomy of compatibility effects, this type of compatibility effect, based on the mapping of a task-relevant stimulus dimension to responses, is classified as a type 2 Ensemble. We will call tasks that involve type 2 ensembles *S-R Compatibility (SRC) tasks*. Kornblum et al. emphasized the role of automatic activation in addition to S-R translation as a primary cause of SRC effects. The extent to which the SRC effect reflects intentional translation versus automatic activation remains a subject of some debate (Proctor & Wang, 1997; Wascher, Schatz, Kuder & Verleger, 2001).

A compatibility effect also occurs when there is dimensional overlap between a task-irrelevant stimulus feature and the task-relevant response (Ensemble 3 tasks in Kornblum et al.'s, 1990, taxonomy). The most commonly described Ensemble 3 task is the *Simon task*, in which the task-relevant stimulus dimension is unrelated to the response, but some irrelevant feature of the stimulus shares features with the response. For example, when participants must make a spatial response based on the color of a light that is presented on the left or right side of the screen, response times (RTs) are shorter when the light's location matches that of the response. Since the Simon effect originates in a task-irrelevant stimulus feature that can be ignored during task performance, the processing of this feature is often described as occurring automatically.

It is likely that to some degree compatibility effects in the SRC and Simon tasks share a common cause. In both tasks, the compatibility effect is always contingent on the similarity between stimulus and response features, regardless of the relevance of the overlapping stimulus feature to task performance (Kornblum, 1992; Kornblum et al., 1990). Furthermore, transfer effects have been found when subjects practice an SRC task prior to performing a Simon task (Proctor & Lu, 1999; Proctor, Yamaguchi & Vu, 2007; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). For example, Proctor and Lu (1999) found that the predisposition to respond in a compatible manner to the irrelevant spatial information in the visual Simon task was reversed following 912 trials of responding in a non-corresponding way to the same spatial information in the SRC task.

There are also differences in both tasks. Attending to the spatial feature of the task stimulus is compulsory in the SRC task and not required in the Simon task. Furthermore, when using the same task stimuli and responses, there is a difference in the magnitude of compatibility effects in the SRC and Simon tasks; namely, compatibility effects are larger in the SRC task (50–70 ms or higher) than the Simon Task (around 25 ms; see Umiltà & Nicoletti, 1990). Finally, although Proctor and Lu (1999) found a transfer effect from the SRC task to the Simon task, no transfer was found in the reverse direction – practice on the Simon task did not influence compatibility effects in a subsequently performed SRC task. Thus, it is unclear as to whether compatibility effects in the SRC and Simon tasks reflect the same cognitive mechanism or are at least partially the result of separate mechanisms.

Level of Response Activation

Since the magnitude of the compatibility effect changes depending on the similarity between the stimulus and response sets in a task, it is likely that the automatic response activation elicited

by a stimulus feature also varies in its level of activation. Indeed, the observation that automatic response activation dissipates over time in the standard spatial location Simon task (Hommel, 1993; 1994) implies that this activation may vary in magnitude. As proposed by Kornblum (1992), the amount of response activation caused by a stimulus is positively related to the degree of feature overlap between the stimulus and response. Kornblum (1992) and Kornblum and Lee (1995) described three ways that stimulus and response features may overlap. Conceptual overlap occurs when stimulus and response sets share overlapping conceptual information, such as a left or right response to the words “left” and “right.” Physical, or “mode” overlap (Lu & Proctor, 2001) takes place when stimuli and responses are related to the same modality. For example, when task stimuli are auditory words, mode overlap is greater when responses are spoken words than when they are button presses. Structural overlap occurs, for example, when a saliently ordered set of stimuli such as the numbers “1, 2, 3, 4...” is mapped onto an ordered set of responses such as speaking the letters “A, B, C, D.” Responses are fastest when these two groups match (“A” with “1”, “B” with “2”, etc.) than when they mismatch. In each of these cases, a relationship between features of the task stimuli and responses exists that leads to activation of the response that best matches the presented stimulus; the stronger the relationship the stimulus and response, the larger the predicted compatibility effect.

Temporal overlap between activated responses

The processing of irrelevant information within the Simon task thus represents both the amount of overall stimulus-based response activation and the temporal proximity of this activation to the point of response selection. In the left-right location version of the Simon task, the compatibility effect will be largest when stimulus-based response activation is strong and peaks immediately prior to response selection. If automatic activation occurs too early, it will dissipate before the critical interference stage prior to response selection (De Jong, Liang, & Lauber, 1994; Hommel, 1993; Umiltà & Liotti, 1987). If onset of the automatic activation occurs after response selection but before response execution, then this activation may not be sufficiently developed to lead to interference for the fastest responses (Hommel, 1995; 1996; Lu & Proctor, 1994). The latter case is found in the Stroop task, a paradigm similar to the Simon task in which the goal relevant and irrelevant features of a stimulus promote different response tendencies. Paley and Olson (1975) proposed that the automatic activation of an irrelevant stimulus dimension only occurs if a response has not yet been selected based on the relevant dimension. Therefore, if presentation of the irrelevant stimulus feature is sufficiently delayed, it no longer affects response behavior.

Reducing the discriminability of environmental stimuli

The degree of similarity between stimulus and response features and the timing of stimulus processing are not the only determinants of the size of compatibility effects. Although compatibility effects are generally considered the result of automatic activation of the response that best corresponds to features of the task stimulus, the magnitude of this automatic response activation may also be related to the ease with which task stimulus features can be identified, which we will refer to as their discriminability. Numerous variations of the SRC and Simon tasks have been used over the last 50 years, but only a handful of studies have manipulated the quality of the stimulus within the task, and the effect that this has on compatibility effects remains unclear. One possibility is that reducing the discriminability of a stimulus may harm overall RT and accuracy, but not influence compatibility effects, since stimulus degradation influences the perceptual processing stage and compatibility effects originate in the later response-selection stage of task performance (Adam, 2000; Christensen, Ford & Pfefferbaum, 1996; Frowein & Sanders, 1978; Simon, 1982; Stoffels, Van der Molen, & Keuss, 1985). This research shows that stimulus quality and compatibility effects are largely independent from one another, commonly leading to additive effects on RTs. For example, Adam (2000) presented participants with an SRC task in which participants made left or right responses

based on whether an “X” target appeared on either the left or right side of the screen. The discriminability of the target’s location was manipulated by varying the distance of the targets from the center of the screen; the greater this distance, the more distinguishable the target location. RTs were shorter overall when the target location was easier to discriminate, but this did not influence the magnitude of the compatibility effect.

Christensen et al. (1996) found a similar result when they examined the influence of stimulus discriminability on compatibility effects elicited by centrally presented location words by adding a white noise overlay over target word stimuli. Left or right responses were made to the words “LEFT” or “RIGHT” written in either upper- or lower-case letters. The response criterion was the word meaning, the case of the word, or both. In the framework of the current study, the word-meaning response and case response tasks were versions of SRC and Simon tasks, respectively. Christensen et al.’s results showed that reducing the general visual quality of the target did not significantly influence the compatibility effect in the SRC version of the task. The compatibility effect was slightly reduced by lowering stimulus discriminability in the Simon task (from 9 ms to –3 ms), but the effect was very small and not significantly different from zero in either condition.

However, there is also evidence that automatic response activation is influenced when specific stimulus features are made less discriminable. There are two ways in which this may influence compatibility effects. First, lowering the discriminability of stimulus information may reduce the overall strength of automatic response activation and therefore lead to a diminished influence on response behavior. Second, reducing discriminability may not change the overall amount of automatic response activation but rather increase the duration of time required for this activation to occur. Evidence for this delay is apparent in both increasing RTs and neural activation associated with stimulus identification (P300 latencies) when the quality of a target stimulus is degraded (Pfefferbaum et al., 1986). This delay likely reflects an increase in the duration of stimulus processing, which postpones the onset of response selection (Christensen et al., 1996; McCarthy & Donchin, 1981). Since automatic activation of the response corresponding to the target stimulus occurs quickly and then decays, a delay in selection of the task-relevant response leads to a decrease in the amount of temporal overlap of the selected response and the automatically activated response, and therefore less response interference and smaller compatibility effects (Hommel, 1993). Conversely, if automatic activation of the corresponding response is delayed, then this activation may not be fully developed when the task-relevant response is selected, and once again there is less overlap between responses and smaller compatibility effects. It is important to note that the overall level of automatic response activation and the amount of overlap between this activated response and activation of the task-relevant response may occur separately and both contribute to the magnitude of compatibility effects. A goal of the current article to distinguish which of these factors, if either, is at play when the visual discriminability of a task stimulus is reduced.

Rationale for Current Study

Previous studies have utilized various forms of degradation of the relevant feature (Hommel, 1993) or both the relevant and irrelevant features of the task stimulus together in order to reduce their discriminability (Christensen et al., 1996). To form a clearer picture of the role of visual stimulus quality in compatibility effects, it is necessary to independently vary the discriminability of stimulus features along with their task relevance. Additionally, since the current experiments examine compatibility effects when the spatial feature of the stimuli is both task-relevant in the SRC task and task-irrelevant in the Simon task, it is possible to directly compare the magnitude of the compatibility effect in both cases for each participant. Although Kornblum (1992) suggested that the mechanism underlying SRC and Simon task compatibility effects is the same, with-participant correlations between the two have yet to be examined. If

the sizes of the compatibility effects in the SRC and Simon tasks are strongly correlated with one another, it is likely that they share a common underlying cause.

In the current experiments, participants performed a choice response task in which spatial information conferred by the task stimulus was either relevant (SRC task) or irrelevant (Simon task) to selecting the appropriate response. Additionally, we changed the amount of stimulus processing that occurs by varying the visual quality of the spatial feature of the stimulus (Experiment 1) or both the spatial and non-spatial stimulus features (Experiment 2). The use of both the SRC and Simon tasks allows for a check of this visual discriminability manipulation. When the spatial feature has low discriminability, overall RTs should increase for the SRC task but not the Simon task since identifying this feature is a response requirement in the SRC task but not in the Simon task. When both the spatial and non-spatial features have low discriminability, overall RTs should increase for both the SRC and Simon tasks. Additionally, the error rate in the SRC task serves as an indicator of the legibility of the word. The goal of the discriminability manipulation is to reduce word legibility but not make the word illegible. Therefore, low discriminability of the location word should increase the time required to read the word but not the success in identifying the word, as measured by the percentage of errors.

There are several reasons why spatial information in the SRC and Simon tasks in the current experiments is conferred by centrally-presented location words rather than the location of a target stimulus. First, information about the side of a stimulus is difficult to make less distinct, since categorizing the location (left versus right) occurs in reference to other stimulus locations. Thus, relative stimulus locations that are close together are as easy to categorize as locations that are further apart. Furthermore, increasing the distance between two response locations also increases the retinal eccentricity of the stimulus, leading to increased difficulty in processing both the task-relevant and irrelevant stimulus features (Hommel, 1993). Since retinal eccentricity and spatial location are confounded with one another, it is difficult to make the location of a stimulus more discriminable without also reducing the visual quality of other features. Location words avoid this problem since spatial information is conferred by the meaning of the word without the need to vary the location of the target stimulus.

Experiment 1

The primary purpose of Experiment 1 was to determine whether lowering the discriminability, or legibility, of a location word by including a black-and-white noise overlay reduces the compatibility effect in the Simon task. In the SRC task, the word direction is required to perform the task, whereas in the Simon task, the word direction is irrelevant for selecting the correct response. Consequently, in the SRC task, reducing the discriminability of the spatial feature should cause an increase in RTs but not affect the compatibility effect (Christensen et al., 1996). In contrast, in the Simon task, it is predicted that a main effect should be found for compatibility, but not discriminability, since the relevant response feature, the color of the word, remains largely intact with the black-and-white noise overlay. If the lowered discriminability of the task-irrelevant spatial information reduces the level of automatic response activation or decreases the amount temporal overlap, then an interaction should be found between the factors of Compatibility and Discriminability. Specifically, the compatibility effect should occur when discriminability is high and be greatly reduced or eliminated when it is low. If degrading the irrelevant stimulus does not reduce its influence, then, as in the SRC task, the influence of the Discriminability and Compatibility factors on RTs should only be additive.

Method

Participants—Thirty-two undergraduate students (21 male, 11 female) ranging in age from 18 to 20 and enrolled in Introduction to Psychology participated in the experiment in return for extra credit in the course.

Apparatus and stimuli—The experiment was written using version 1.2 of E-Prime on PC-compatible machines running the Windows XP operating system. The stimuli were presented on 14 inch VGA monitors. Responses to the stimuli were made by either pressing the ‘Z’ or ‘M’ buttons on a QWERTY keyboard with the left or right index fingers, respectively. The visual stimuli were the words “LEFT” or “RIGHT” that were colored red or green and presented on a white background. The words were made from lines that were two pixels wide. Each word was presented at the center of the screen. The word “LEFT” was 5-cm wide and “RIGHT” was 6-cm wide. Both of the words were 1.5-cm high. Participants sat 60-cm away from the screen. For the conditions with low discriminability of the spatial feature, a 9.5-cm wide, 7.5-cm high rectangle noise mask was centrally placed over each word stimulus. Noise was generated in this area which included the word by randomly replacing 65% of the pixels with one of 256 shades of grey ranging from pure white to pure black. Four different randomized noise masks were created for each of the four types of stimuli (green and red colored “LEFT” and “RIGHT”).

Procedure—Each participant performed the Simon task and the SRC task both without and with the noise overlay (high and low discriminability, respectively). For the Simon task, participants were instructed to make left or right responses based on the color of a centrally presented word (“LEFT” or “RIGHT”) and that the actual word was irrelevant to the task. In the SRC task, the stimuli were identical, but the relevant stimulus feature was the word meaning. Therefore, the conditions were the Simon task and Compatible and Incompatible versions of the SRC task, either with or without a black-and-white noise overlay. Participants performed 2 blocks of 128 trials of the Simon task with the noise overlay and 2 blocks without the noise overlay. Participants also performed 1 block each of the compatible and incompatible versions of the SRC task with and without the overlay. Condition order was counterbalanced between participants with the stipulation that the Simon task always occurred before the SRC task in order to avoid potential transfer effects (Procter & Lu, 1999). For the Simon task, half the participants responded left to a red-colored word and right to a green-colored word and the other half used the reverse mapping.

At the onset of each condition, participants were provided with on-screen instructions about how to respond to the stimuli, followed by 8 practice trials. Following the practice trials, participants performed 2 blocks of 128 trials in the Simon task conditions and 1 block of 128 trials in the Compatible and Incompatible SRC conditions. The practice trials were excluded from the final analysis. Each trial began with a blank white screen for 500 ms, followed by a centrally presented fixation (asterisk) in black for 1000 ms. The word stimulus then appeared and remained on the screen until a response was made. If an early response was made, a tone sounded and the words “You responded too early” appeared on the screen for 2500 ms and the trial ended. If an incorrect response was made to the word stimulus, the same tone sounded and the words “Incorrect!” appeared on the screen for 1000 ms.

Results

Trials with RTs shorter than 150 ms or longer than 1500 ms, which amounted to 1.85% of total trials, were excluded from analysis. Separate 2x2 within-subject ANOVAs were run on the Simon and SRC task for the factors of Compatibility (Compatible versus Incompatible) and Discriminability (High vs. Low). RTs and percent error (PE) for both tasks are shown in Figure 1.

Simon task—For the Simon task, an ANOVA of mean RTs showed significant increases in RTs for incompatible trials $F(1, 31) = 20.26, p < .001, MSE = 613$ and with low discriminability, $F(1, 31) = 7.80, p = .009, MSE = 4,313$. In addition, the compatibility effect was significantly smaller with low discriminability ($M = 8$ ms) than with high discriminability ($M = 31$ ms), $F(1, 31) = 10.23, p = .003, MSE = 407$. PE showed a similar reduction in the compatibility effect in the low discriminability condition, $F(1, 31) = 13.41, p = .001, MSE = 3.92$. Additionally, PE increased in incompatible trials compared to compatible trials, $F(1, 31) = 22.19, p < .001, MSE = 4.74$, and with low discriminability versus high discriminability, $F(1, 31) = 19.44, p = .001, MSE = 3.11$.

SRC task—RTs and PE for the SRC task are shown in Table 1. Since the meaning of the word must be identified in order to select the appropriate response, it was hypothesized that RTs would increase with reduced discriminability. An ANOVA of the mean RTs for the SRC task yielded a significant RT increase both in incompatible versus compatible trials $F(1, 31) = 71.56, p < .001, MSE = 5,452$, and in trials with low versus high discriminability, $F(1, 31) = 206.57, p < .001, MSE = 3,880$. As expected, there was no difference in the size of the compatibility effect in the high ($M = 112$ ms) and low ($M = 108$ ms) discriminability conditions, $F(1, 31) = .08, p = .79, MSE = 1,600$. PE showed a similar pattern to RT. PE was higher for incompatible than compatible trials, $F(1, 31) = 22.39, p < .001, MSE = 10.20$, and higher in the low versus high discriminability condition, $F(1, 31) = 10.57, p = .003, MSE = 5.60$. As with RTs, there was no interaction between Compatibility and Discriminability, $F(1, 31) = .03, p = .85, MSE = 5.66$.

In the SRC and Simon task conditions with high discriminability, compatibility effects were again calculated for each individual by finding the RT difference between incompatible and compatible trials. Using a Pearson's correlation coefficient, a moderately sized positive relationship was found between the compatibility effects in both of these tasks, $r(32) = .47, p = .007$ (see Figure 2).

Discussion

The goal of Experiment 1 was to lower the visual discriminability of the spatial information conferred by the location word (legibility), but not that of the non-spatial information (color). Reduction of the word legibility was confirmed by a large increase in RTs when this information was required in order to select a response in the SRC task. However, the current manipulation was not completely successful at leaving the visual quality of the non-spatial information intact, since RTs also increased when only the word color was required for response selection in the Simon task. Nonetheless, based on the fact that the discriminability manipulation had a much larger effect on RTs in the SRC task (158 ms increase) than the Simon task (32 ms increase), $F(1, 31) = 59.02, MSE = 4,293, p < .001$, it can be inferred that the noise mask reduced the discriminability of the spatial information to a much larger degree than the non-spatial information. Furthermore, although error rates increased under low discriminability for the SRC task, PE remained low, suggesting that although processing the word took longer, the word remained legible.

The reduction in the Simon effect that occurs with reduced discriminability of the spatial stimulus feature may be explained by a lack of processing of the irrelevant spatial stimulus feature or a reduction in temporal overlap of controlled and automatic response-selection processes. In the former case, the spatial feature was simply not identified to a sufficient degree in order to interfere with response behavior. In the latter case, the spatial feature is still fully identified, but this processing is delayed until after response selection has successfully occurred. To discriminate between these two possibilities, the compatibility effect was calculated at each Vincentized quartile range of the response distributions (Ratcliff, 1979) for the Simon task

(Figure 3). If RT distributions in Experiment 1 show a delay in the increase of the compatibility effect in the Simon task, it is likely that reduction of spatial feature's discriminability simply delayed its automatic activation as proposed by temporal overlap account. However, if the compatibility effect remains both negligible and stable across the entire distribution, then reduced discriminability led to less overall automatic response activation compared to the intact version.

RT distributions in Experiment 1 support this latter view. The RT distributions show a slight increase across RT quartiles in the low discriminability condition (−2 ms, 1 ms, 1 ms, 10 ms), which is much smaller than in the high discriminability condition (12 ms, 14 ms, 24 ms, 61 ms). An ANOVA confirmed that the compatibility effect is significantly smaller across the entire RT distribution for low discriminability, $F(1, 31) = 10.41$, $MSE = 3,852$, $p = .003$, and does not increase to the same degree across the quartile range as the high discriminability condition, $F(3, 93) = 7.78$, $MSE = 615$, $p < .001$. Furthermore, paired sample *t*-tests of compatible versus incompatible trial RTs at each quartile found that the compatibility effect was always significantly different from zero in the high discriminability condition (all $ps < .05$), but never in the low discriminability condition (all $ps > .29$). In other words, low discriminability of the irrelevant stimulus feature seemingly reduced the overall amount of automatic response activation rather than delaying it, thus supporting the level of activation account. However, reducing the discriminability may have delayed automatic response activation to a great enough degree that it would not occur until after the longest RT quartile (611 ms). This latter possibility is likely, since the mean RT to this same spatial information when it was task-relevant in the SRC task was 646 ms, longer than even the slowest responses to the intact non-spatial information in the Simon task.

Experiment 2

Results so far found a reduction of the compatibility effect in the verbal Simon task when the discriminability of the spatial feature was reduced. In Experiment 2, both the spatial and non-spatial features of the task stimulus were reduced in discriminability. There are two likely outcomes in this case. The compatibility effect may be reduced whenever the discriminability of the spatial feature is lowered. In this scenario, lowering the discriminability of the spatial feature also reduces the overall automatic activation of the corresponding response. Alternatively, the compatibility effect may be restored if the discriminabilities of both the spatial and non-spatial features are reduced because the processing of both is delayed by a roughly equivalent amount. Consequently, automatic response activation and response selection still temporally overlap with one another to the same degree as in the high discriminability condition. This latter scenario is predicted by the temporal overlap account but has not been directly tested to our knowledge.

Method

Participants—Thirty undergraduate students (16 male, 14 female) ranging in age from 17 to 20 years old that were enrolled in Introduction to Psychology participated in the experiment in return for extra credit in the course.

Procedure—The design was similar to Experiment 1 and used stimuli very similar to those of Christensen et al. (1996) and Pfefferbaum et al (1986). However, instead of varying the color of the words “LEFT” and “RIGHT,” the letters themselves were varied so that they were either uppercase or lowercase. The words were always presented in black. Therefore, the spatial feature was once again the meaning of a directional word but the non-spatial feature was now the word case. The noise overlay was produced in an identical fashion to Experiment 1. The critical difference in the current experiment is that the discriminability of both the spatial and non-spatial features of the stimulus (word meaning and case, respectively) were reduced by

the noise overlay, whereas in Experiment 1 only the discriminability of the spatial feature was reduced.

Results

RTs shorter than 150 ms or longer than 1500 ms were excluded from analysis (2.69% of trials) and separate 2x2 within-subject ANOVAs were run on the Simon and SRC task for the factors of Compatibility (Compatible versus Incompatible) and Discriminability (High versus Low).

Simon task—RTs and PE for the Simon task are shown in Figure 1. As in Experiment 1, RT main effects were found for both the Compatibility $F(1, 29) = 14.80, p = .001, MSE = 1,453$, and Discriminability $F(1, 29) = 79.27, p < .001, MSE = 6,322$, conditions. However, unlike Experiment 1, the compatibility effect was not affected significantly by reducing stimulus discriminability (31 ms with high discriminability and 22 ms with the low discriminability), $F(1, 29) = 1.57, p = .22, MSE = 336$. An ANOVA of RT quartiles found no difference in the magnitude of compatibility effects in the high and low discriminability conditions $F(1, 29) = 1.04, MSE = 2,185, p = .32$, and the compatibility effects in both groups remained the same across the entire RT distribution (Compatibility x Discriminability x RT Quartile), $F(3, 87) < 1.0$ (Figure 3). PE increased for incompatible versus compatible trials, $F(1, 29) = 14.59, p = .001, MSE = 10.41$, but was not affected by the level of discriminability, $F(1, 29) = 1.52, p = .23, MSE = 5.99$, nor the interaction of Discriminability and Compatibility, $F(1, 29) < 1.0$.

As in Experiment 1, a Pearson's correlation coefficient of the RT compatibility effects in the High Discriminability condition of the SRC and Simon tasks found a moderate positive correlation, $r(30) = .40, p = .03$ (Figure 2).

SRC task—RTs and PE for the SRC task are shown in Table 1. For the SRC task, an ANOVA found an increase in RTs for both the incompatible versus compatible trials, $F(1, 29) = 72.8, p < .001, MSE = 2,614$, and when discriminability is reduced, $F(1, 29) = 170.27, p < .001, MSE = 2,459$. As in Experiments 1 and 2, reduced discriminability did not influence the compatibility effect (76 ms with high discriminability and 83 ms with low discriminability) in the SRC task, $F(1, 29) < 1.0$. PE showed a similar pattern, with an increase in errors on incompatible trials, $F(1, 29) = 25.43, p < .001, MSE = 10.27$, and with low discriminability, $F(1, 29) = 9.24, p = .005, MSE = 1.67$, but no interaction between Compatibility and Discriminability, $F(1, 29) = 2.00, p = .17, MSE = 2.61$.

Discussion

The discriminability manipulation in Experiment 2 was successful at reducing the quality of both the spatial and non-spatial features of the location word, as evidenced by a roughly equivalent increase in RT in the low discriminability conditions of both the SRC and Simon tasks (118 ms and 129 ms respectively), $F(1, 29) < .1.0$. Once again, lowered discriminability increased PE in the SRC task, but overall PE was low. The compatibility effect in the Simon task remained unaffected by the discriminability manipulation, suggesting that reducing the legibility of the word did not reduce the overall level of automatic response activation. Rather, reducing the discriminability of both the irrelevant and relevant stimulus features delayed responding but retained temporal overlap and the interference between automatic response activation and response selection.

General Discussion

The goal of the current research was to examine the influence of discriminability of the task-relevant and irrelevant stimulus features on the compatibility effect in location word versions of the Simon task. Three main conclusions can be drawn from the current results. First, reducing

the discriminability of the irrelevant stimulus feature delayed automatic response activation until after response selection had taken place, as evidenced by the non-significant Simon task compatibility effect across the entire RT distribution in Experiment 1. Hommel (1996) suggested that in some cases, such as simple RT tasks, response selection occurs before compatibility effects have enough time to develop to an observable level. This view is confirmed by the results of Experiment 2 - when discriminability of both the irrelevant and relevant response features were reduced, the Simon effect was restored to the same size as when there was no stimulus degradation at all. According to the temporal overlap account, degrading the quality of the task-relevant and irrelevant features at the same time delayed processing of both, thereby increasing overall RTs but not changing the amount of overlap between response selection and automatic response activation. Consequently, the size of the compatibility effect remained unchanged. This interpretation is applicable to previous studies that found no change in compatibility effects following the general degradation of task stimuli (Adam, 2002; Christensen et al., 1996; Hasbroucq, Guiard, & Kornblum, 1989)

Although the current data favor a temporal overlap account of compatibility effects, a level of activation account cannot be fully ruled out. There is some evidence that automatic response activation in the Stroop color-naming task, a task that is similar to the Simon task, is sensitive to attention. For example, Kahneman and Chajczyk (1983) found that the influence of a flanker word is diminished when presented in conjunction with additional distractor words, suggesting that lexical processing is strongly related to attention demands (for an alternative account, see Brown, Roos-Gilbert, & Carr, 1995). Furthermore, Lien et al. (2008) found that a secondary task can attenuate the semantic processing of words. Degrading task-irrelevant spatial information in the Simon task may also minimize processing of the spatial information conveyed by a location word and reduce the overall level of automatic response activation, thereby lowering its interference with response selection and eliminating the compatibility effect in Experiment 1. Additionally, the compatibility effect in the low discriminability version of the Simon task remained small across the entire RT distribution, which would be expected if automatic response activation were minimized.

However, an activation account has more difficulty explaining the existence of a compatibility effect in Experiment 2, in which the discriminability of the task-relevant feature was reduced along with the task irrelevant feature. In terms of an overall level of activation account, the degradation of the task-irrelevant spatial information should always lead to a weaker automatic activation of the corresponding response. It is possible that degradation of the task-irrelevant feature in the Simon task may have indeed reduced the overall level of automatic response activation. However, the task-relevant feature now required additional processing in order to select the correct response, and this additional processing led to increased activation of the task-irrelevant feature, thereby restoring its influence on behavior. If this is the case, then the magnitude of response activation is determined by at least two factors: automatic activation of the response by the task-irrelevant stimulus feature and the amount of attention allocated to processing the feature.

Second, we showed that temporal overlap is a factor when spatial information is conferred by location words as well spatial locations. Temporal overlap predicts that compatibility effects will be reduced either when task-irrelevant stimulus information is delayed by reduced visual discriminability and thereby not fully established prior to response selection, or when the task-relevant information is delayed, allowing the activation of spatial information to decay. The latter of these predictions is well established in spatial location Simon tasks (for review, see Lu & Proctor, 1995). Since word-based compatibility effects increase rather than decay at longer durations (Proctor, Yamaguchi, & Vu, 2007), delaying response selection in the high discriminability versions of the Simon task does not reduce compatibility effects at the longest part of the RT distribution in the current experiments. However, we provided evidence that

reducing the legibility of the word leads to a reduction in the compatibility effect, and this is likely due to the delay, and not the elimination, of automatic activation of the corresponding response. This finding is consistent with the view that when attention is allocated to a word's location its processing is obligatory. Although task-irrelevant word processing may be delayed by reducing its visual quality (Experiment 1), it nonetheless occurs when there is sufficient time prior to response selection (Experiment 2).

Third, compatibility effects originating in both task-relevant and task-irrelevant stimulus dimensions are moderately correlated (r 's between .40 and .50) with one another. To our knowledge, this is the first correlational analysis between compatibility effects in the SRC and Simon tasks. The relationship between SRC and Simon task compatibility effects has been contested over the years (see, e.g., Hasbroucq & Guiard, 1991). However, as evidenced by the consistent correlation between SRC and Simon task compatibility effects in both of the current experiments, it appears that location word compatibility effects share some common underlying factor regardless of whether the spatial feature of the stimulus is relevant or irrelevant to response selection. The current research does not provide evidence concerning the nature of these shared factors. However, as mentioned in the introduction, since compatibility effects in the Simon task originate in task-irrelevant stimulus information they may be caused by automatic response activation rather than stimulus-response translation. This is less clear for compatibility effects in the SRC task, which are usually attributed to either more complicated stimulus-response translation in incompatible trials, automatic activation of the corresponding response, or a combination of both. If the compatibility effect in the Simon task cannot be attributed to stimulus-response translation, then the shared variance between the Simon and SRC task is likely due to a factor related to automatic response activation. Other than the current research, direct comparisons of the individual variability across multiple forms of compatibility tasks have yet to be performed and may be fruitful in better understanding the mechanisms that underlie this phenomenon. Furthermore, it is unknown whether different types of compatibility effects such as those found for spatial or symbolic locations are also due to the same underlying mechanisms as well.

Conclusion

The current experiments provide a detailed depiction of the influence of visual stimulus discriminability on compatibility effects in the SRC and Simon tasks. Together, the results of each of the current experiments support the temporal overlap account of compatibility effects and extend it to include irrelevant spatial information conveyed by location words. We show that reducing the visual discriminability of irrelevant spatial information in word stimuli delays the automatic activation of a corresponding response, but does not eliminate it. This finding is currently limited to a pure-block, discrete manipulation of individual feature discriminability; it is of interest to examine a more continuous manipulation (see e.g., Bosbach, Prinz, & Kerzel, 2004). For example, our current conclusions would predict that the closer the discriminability between the task-relevant and irrelevant features, the larger the compatibility effect in the Simon task. This should hold true regardless of the overall level of discriminability, as long as these features remain identifiable.

Lastly, although various models presuppose some relation between various forms of compatibility effects, we provide a correlational analysis that shows a clear relationship between word-based compatibility effects when they originate in either task-relevant or task-irrelevant stimulus features. However, this relation accounts for only a portion of the variability in the current experiments, and a more comprehensive multivariate approach is needed to examine the unique cognitive components that distinguish between compatibility effects in the SRC and Simon tasks.

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Figure 1. Response time (RT) and percent error (PE) with standard errors for compatible and incompatible trials in the Simon task in Experiments 1 and 2. The discriminability of the spatial information (word legibility) was either high or low.

Figure 2. Scatterplot with regression lines for Z-scores of compatibility effects in the high-discrimination conditions of the SRC and Simon tasks in Experiment 1 (open circles, solid line) and Experiment 2 (filled circles, dotted line).

Figure 3.

Compatibility effects at each response time quartile for high (filled circles) and low (open circles) stimulus discriminability conditions in the Simon task in Experiments 1 and 2. Exp 1 = task-irrelevant feature discriminability manipulated, Exp 2 = task-irrelevant and task-relevant discriminability manipulated.

Table 1
SRC task Response Time (RT) and Percent Error (PE) as a function of compatibility and discriminability (Exp.1 and 2).

Discriminability	Compatibility					
	Compatible		Incompatible		Compatibility Effect	
	RT	PE	RT	PE	RT	PE
High	491	2.63	<i>Experiment 1</i>		112	2.59
Low	652	3.91	604	5.22	108	2.75
			760	6.66		
High	504	1.93	<i>Experiment 2</i>		76	2.54
Low	619	2.23	580	4.47	83	3.37
			701	5.6		