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# Selective Attention and the Perception of an Attended Non-target Object

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## Abstract

Although many theories of attention assume that attending to an object results in the processing of all its feature dimensions, there has been no direct evidence that the irrelevant dimensions of an attended non-target object are encoded. This article explores factors that modulate such processing. In six experiments, participants made a speeded response to a probe preceded by a prime that varied in two dimensions. Their reaction times to the probe were influenced by the response compatibility between the relevant and irrelevant dimensions of the prime. Furthermore, the effect was observed only when attention was directed to a non-location object feature and when participants' reaction times were relatively long. These results suggest that the effect of attention on a non-target object is more complex than was previously understood.


*Keywords:* attention, selection, distractor processing, perception of an attended nontarget object

# Selective Attention and the Perception of an Attended Non-target Object

Many theories of visual attention assume that when an object is attended, all of its feature dimensions are processed regardless of an observer's behavioral goals (e.g., Duncan, 1984; Kahneman & Henik, 1981; Kahneman & Treisman, 1984). In other words, the allocation of attention to an object leads to the encoding of the entire object. Once an observer has focused attention on an object, it is no longer possible to limit his or her processing to only the task-relevant dimension. All of the feature dimensions that belong to the object are processed instead, despite the fact that doing so may be undesirable under some circumstances.

However, this assumption was recently challenged by several experiments in which participants failed to process the irrelevant dimension of an attended object when that object was not a target (Remington & Folk, 2001; Yang & Kim, 2003). These experiments suggest that attention does not necessarily encompass the encoding of all the feature dimensions that belong to the same object. The effect of attention may depend on the status of the attended object as being a target or a distractor.

The purpose of the present article is to identify factors that modulate the effect of attention on the selection of a non-target object. To be consistent with Remington and Folk (2001), in the present article the word *attention* (or *attend*) refers to the act of paying attention, and *selection* (or *select*) to the processing or encoding of a stimulus. Two issues are examined in this article: (a) whether the nature of the specific feature dimension that receives attention modulates the effect of attention on selection and (b) whether the processing time available for an attended non-target object influences its degree of encoding.

## Evidence That Attention Entails Selection

The most famous example that supports the notion of a direct link between attention and selection is perhaps the Stroop experiments (Stroop, 1935). In a typical experiment, participants are required to identify the color of a printed word that is itself a color name (e.g., the word *RED* written in green color). When the meaning of the word and its color are incongruent, reaction times are longer than when the two are congruent or unrelated. This phenomenon has been referred to as the Stroop interference effect. Not only has the effect been observed in a wide variety of paradigms (see MacLeod, 1991, for a review) but it has also been demonstrated to correlate positively with the amount of attention a stimulus receives. For example, it was reported that Stroop interference was larger when an incongruent stimulus appeared within an attended object rather than within an unattended object (Kahneman & Henik, 1981) or when it was preceded by a valid cue relative to an invalid cue (Chen, 2003b).

Other evidence that indicates a close relationship between attention and selection can be found in experiments that use the flanker paradigm (B. A. Eriksen & Eriksen, 1974), in which participants respond to a central stimulus flanked by two distractor stimuli. It has been shown that participants' reaction times are prolonged by incompatible distractors indicating a different response from the target relative to neutral distractors that are not associated with any responses. Furthermore, the response compatibility effect correlates negatively with the separation between the target and the distractors, suggesting that the amount of attention influences the degree of processing of the irrelevant flankers (e.g., B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & St. James, 1986; Gatti & Egeth, 1978; Kahneman & Chajczyk, 1983; Miller, 1991; Yantis & Johnston, 1990).

Further illustrations of the effects of attention on selection include experiments on object-based attentional selection. There is ample evidence that attending to a stimulus on one part of an object facilitates the processing of other stimuli that pertain to the same object (see Scholl, 2001, for a review). Following a seminal study by Duncan (1984), many researchers have reported that participants are faster and/or more accurate when responding to two features that belong to a single object compared with two different objects (e.g., Baylis & Driver, 1993; Behrmann, Zemel, & Mozer, 1998; Duncan, 1984). Switching attention within one object is more efficient than switching attention between two objects (e.g., Chen, 1998; Egly, Driver, & Rafal, 1994; Moore, Yantis, & Vaughan, 1998). Interference from irrelevant objects is also larger when they are from the same perceptual group as the target rather than when they are from a different perceptual group from the target (e.g., Driver & Baylis, 1989; Harms & Bundesen, 1983; Kramer, & Jacobson, 1991). Moreover, a positive correlation has been found between observers' response latencies to a target (or targets) and the number of distractors to be filtered out in non-search tasks (e.g., Chen, 2000; Kahneman, Treisman, & Burkell, 1983).

In addition to the above findings, it has been demonstrated that even the task-irrelevant dimension of a distractor can at times be processed. In an experiment designed to test the automaticity of reading, Kahneman and Chajczyk (1983) presented their participants with stimulus displays made of a colored patch and either one or two irrelevant words. The task was to identify the color of the patch as quickly as possible. The most relevant result for the present research was that the participants showed a

Stroop interference effect, suggesting that they processed the meaning of the words despite the fact that the meaning was task-irrelevant and the distractor words were at different locations from the target color patch.

In summary, prior research has accumulated considerable evidence for the selection of the irrelevant feature dimension of a target object as well as a close link between attention and selection (e.g., Baylis & Driver, 1993; Chen, 1998, 2000; Duncan, 1984; Egly et al., 1994; B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & St. James, 1986; MacLeod, 1991). Kahneman and Chajczyk's (1983) study has further suggested that the extent of processing of a distractor may even extend to its irrelevant dimension. Together, these results are consistent with the notion that attending to one dimension of an object leads to the selection of the entire object (Duncan, 1984; Kahneman & Treisman, 1984).

## An Alternative View – The Dissociation of Attention and Selection

Despite the substantial evidence described above, recent experiments suggest that attention does not always result in selection (Remington & Folk, 2001; Yang & Kim, 2003). Remington and Folk noted that evidence supporting the attention-selection assumption was based largely on the results of those experiments in which the attended object was itself a target object (e.g., Baylis & Driver, 1993; Duncan, 1984; Stroop, 1935). In other words, it is unclear whether the processing of an irrelevant object feature was primarily caused by the allocation of attention to the object or by the status of that object as being a target.

To determine whether attention per se would lead to selection, Remington and Folk (2001) dissociated attention from an object's status so that an attended object could be either a target or a distractor. They found that the extent of processing of the attended object depended on the status of that object. For example, in one experiment the participants made speeded response to either the identity (*T* or *V*) or the orientation (left or right) of a red target letter among three white distractor letters. At the beginning of each trial, the participants saw four rectangles together with a task symbol at the center. The rectangles were placeholders that remained on the screen throughout a trial, and the task symbol informed the participants whether they should respond to the target's identity or orientation on a given trial. After a variable delay the cue display appeared. The display was made of three sets of white dots and one set of red dots. Each set consisted of four individual dots, and they were flashed briefly around the rectangles. Because the set of red dots was a color singleton like the target, it was assumed to capture the participants' attention (Folk, Remington, & Johnston, 1992). Shortly after the offset of the cue, the target display, which was made of four letters, appeared inside the rectangles. Of particular interest was whether the participants' response latencies would be influenced by the status of the letter at the cued location. The letter could be a target whose irrelevant dimension was either consistent or inconsistent with the correct response, a neutral item not associated with any responses, or a foil whose relevant or irrelevant dimension was congruent or incongruent with the correct response. The results showed that when the attended letter was a target, both its relevant and irrelevant dimensions were processed. When it was a distractor, only the relevant dimension was encoded. On the basis of these data and comparable findings from a subsequent experiment, Remington and Folk concluded that attention per se does not lead to the selection of all the feature dimensions of an object, and that behavioral goals mediate the extraction of elementary object features when an object has not been selected as a target.

The effect of task relevancy on the processing of distractors has also been investigated by several other researchers who used flanker paradigms with flankers that varied in two featural dimensions (Cohen & Shoup, 1997; Maruff, Danckert, Camplin, & Currie, 1999). Thus, on any given trial the target and flankers could be on the same dimension (e.g., a target defined by color was presented with flankers whose color was either compatible or incompatible with the target's response) or they could be on different dimensions (e.g., a target defined by orientation was presented with flankers whose color was either compatible or incompatible with the target's response). The major finding was that the flankers influenced performance only when they were on the same dimension as the target, such as when both were defined by color or orientation. When they were on different dimensions, the effect of the flankers was negligible (but see Mordkoff, 1998).

However, it should be noted that although the results of the flanker experiments are consistent with Remington and Folk's (2001) account of a dissociation between attention and selection, the allocation of attention was not strictly controlled because these experiments were not designed specifically to investigate the encoding of an attended non-target object. Consequently, as Remington & Folk pointed out, these results cannot be taken as direct evidence to either support or refute the view that attention leads to selection.

## Overview of the Present Study

The Remington and Folk (2001) study underscored the importance of identifying factors that modulate the effects of attention on selection. A key feature of their study was the use of spatial attention. It is important to point out that Remington and Folk did not use a location task. However, the specific design of their experiment made it likely that immediately before the onset of the target, the participants were attending to the location indicated by the cue. Recall that the stimulus locations were marked by the rectangular placeholders that remained visible throughout a trial. Because the target could appear only in one of the rectangles shortly after the flash of the cuing dots, it would be reasonable for the participants to attend to the region of space within the rectangles. If the onset of the red dots indeed captured the participants' attention to the cued location, this leads to the question of whether a dissociation between attention and selection would still exist if attention were paid to a non-location object feature such as color or shape. In light of the many differences regarding the role of location versus the role of color or shape in selective attention (see Lamy & Tsal, 2001, for a review) and the many differences between object-based and location-based attentional selection (see Cave & Bichot, 1999, for a review), it is possible that whereas attending to the location of an object may not result in the processing of the other irrelevant feature dimensions as shown by Remington and Folk, attending to a non-spatial aspect of an object may lead to their selection.

Evidence in support of the above speculation is implicated in the study of Kahneman and Chajczyk (1983). Recall that the participants were required to identify the color of a color patch, and their reaction times were influenced by the meaning of the irrelevant words. If one assumes that participants directed their attention in accordance with the requirement of the task, the interference effect suggests that they processed the irrelevant dimension of the distractor words when the task-relevant dimension was color. More recently, Henik and his colleagues (Henik, Ro, Merrill, Rafal, & Safadi, 1999) examined the conditions under which an irrelevant color word would affect the processing of a color patch. They found that the participants' performance was influenced by both the color and the meaning of the word, suggesting that the relevant as well as the irrelevant dimensions of the word were processed. Subsequent experiments further indicated that the degree of processing was modulated by the participants' task (color vs. meaning identification) and their mode of response (i.e., manual vs. vocal response). Taken together, these results suggest that in addition to the status of an object, other factors may affect the degree of processing of an attended non-target object. However, because these experiments all used Stroop color words as the critical non-target stimuli, the response codes between the target and the irrelevant dimension of the distractor (e.g., the meaning of the word *RED*, *GREEN*, or *YELLOW*) were identical. Given that reading is an involuntary process for most people, it is unclear whether similar results could be generalized to other visual stimuli.

With a two-dimensional prime, the experiments reported in this article used a novel approach to investigate the relationship between attention and selection. On each trial participants saw three consecutive displays consisting of a response cue, a prime, and a probe. The task was to make a speeded response to a specific feature of the probe as required by the response cue on a given trial. Thus, the present experiments differed from other studies in two important ways. First, unlike previous studies that used a spatial cue to guide participants' attention to the location of a critical object prior to its onset (e.g., Remington & Folk, 2001), the current experiments used the abrupt onset of the prime as an effective cue to direct participants' attention to the prime (e.g., Theeuwes, Kramer, Hahn, & Irwin, 1998; Yantis & Jonides, 1984; 1990). If one assumes that participants would focus attention to the task-relevant dimension, such a design would allow the manipulation of the specific feature dimension that received attention. Second, to maximize the allocation of attention to the prime, instead of presenting the target and distractor(s) simultaneously, I showed the prime and probe sequentially. It was hoped that this would prevent the probe from competing with the prime for attentional resources while the prime was being displayed. Experiment 1 required participants to respond to either the color or the orientation of the probe on different trials. The goal was to investigate whether attending to a non-location object feature such as color or orientation would result in the selection of both the relevant and irrelevant dimensions of the prime. Experiment 2 determined whether the selection of the prime would be modulated by the nature of the specific feature dimension that received attention, in that whereas attending to location would not elicit the processing of the irrelevant prime dimension, attending to shape would lead to its selection. Experiments 3 and 4 explored whether the results of the previous two experiments were independent of the positive correlation between the relevant dimensions of the prime and probe. Experiments 5 and 6 tested the hypothesis that the amount of processing time available for the prime would also modulate its extent of processing. Together, these experiments identified factors that influence the selection of an attended non-target object and sought the boundary conditions under which attention leads to selection.

## Experiment 1

The goal of Experiment 1 was to investigate whether the irrelevant dimension of a non-target object would be processed when attention had been directed to a non-spatial feature of that object. The participants viewed a response cue followed by two successive displays of a prime and a probe, each consisting of a single, colored line. The task was to make a speeded response to either the color of the probe (red or green) or its orientation (left or right tilted) depending on the specific response cue that was shown at the beginning of a trial. Because the prime was a stimulus that varied in color and orientation, by manipulating the response compatibility between its two featural dimensions, inferences could be made regarding the processing of its irrelevant dimension. Of particular interest was whether attending to one dimension of the prime would lead to the selection of the other, irrelevant dimension. Should such processing occur, the participants would be faster when the relevant and irrelevant dimensions of the prime were compatible than when they were incompatible.

*Method*

*Participants*. Twenty-one University of Canterbury undergraduate students took part in the experiment in exchange for payment. All of them reported to have normal or corrected-to-normal vision.

*Apparatus and Stimuli*. Stimuli were shown on a Power Macintosh 6100/66 computer with a 13-in RGB monitor. An experimental program, MacProbe (Hunt, 1994) was used to present stimuli and to record responses. Participants viewed the stimuli from a distance of approximately 60 cm in a dim room.

Each trial consisted of three displays: a response cue, a prime, and a probe (see Figure 1). The response cue was either a white letter *C* or *O* presented in 36-point Geneva font at the center of the computer screen. Both the prime and probe were made of a single colored line subtended $1.1^0$ x $0.19^0$ of visual angle in length and width. The prime was a red or green line tilted $45^0$ left or right on two-thirds of the trials. On the remaining ones, its color and orientation depended on the specific response cue on a given trial. When the task was to report color, the prime was either red or green with a horizontal orientation. When the task was to report orientation, the prime was white with a $45^0$ left or right tilt. Variation of the probe occurred in only one of the dimensions: it was a vertical red or green line on color trials, and a blue line tilted $45^0$ left or right on orientation trials. To avoid the potential effect of masking, I designed the experiment such that the prime and probe appeared at different sides of the screen, $5.5^0$ from the center.

The participants were instructed to respond to the color or orientation of the probe on the basis of the response cue, with a *C* referring to *color* and an *O* to *orientation*. Thus, on every trial, there was a relevant dimension as well as an irrelevant one. The participants were provided with two response keys, for which they used the forefinger of their dominant hand to press the < key if the response was either *red* or *left* and the middle finger to press the > key if the response was *green* or *right*. Although no response was required of the prime, attention to it was ensured by making its appearance an abrupt onset. Previous research has shown that abrupt visual onsets capture attention (e.g., Theeuwes et al., 1998; Yantis & Jonides, 1984, 1990).

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Insert Figure 1 about here

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*Design and Procedure*. The experiment used a within-participants design, with the principal manipulations being prime-probe similarity (same or different) and intra-prime compatibility (compatible, incompatible, or neutral). The prime-probe similarity refers to the *inter-object* relationship between the relevant dimensions of the prime and probe. To encourage participants to attend to the prime, I made its relevant dimension was the same as that of the probe on two-thirds of the trials and different on the remaining ones. The intra-prime compatibility refers to the *intra-object* response compatibility between the relevant and irrelevant dimensions within the prime. They were equally likely to be compatible (i.e., when they indicated the same response key), incompatible (i.e., when they indicated different response keys), or neutral (when the irrelevant dimension was not associated with any response keys). There were six experimental conditions: same-compatible, same-incompatible, same-neutral, different-compatible, different-incompatible, and different-neutral, in which the first word refers to the inter-object relationship and the second word to the intra-prime compatibility.

To visualize the various conditions, consider a trial that consists of the letter *C*, a green line with a right tilt, and a red vertical line. The relevant dimension is color, and the correct response should be *red*. This trial belongs to the different-compatible condition. The prime-probe similarity is different because the prime is green and the probe is red. The intra-prime compatibility is compatible, because the two dimensions of the prime, i.e., the color *green* and the orientation *right*, are associated with the same response key.

On each trial, the response cue was presented at the center of the screen for 1005 ms. Upon its offset, the prime appeared for 120 ms at either the left or right side of the screen with equal probability, followed immediately by the presentation of the probe for 120 ms at the opposite side of the screen. The inter-trial interval was 1,500 ms. The participants were instructed to maintain fixation at the location of the cue and to make a speeded response to the probe. Both speed and accuracy were emphasized. After 60 practice trials, they performed three blocks of 192 trials. The experiment took approximately 40 min to complete.

*Results and Discussion*

Table 1 lists the participants' mean reaction times and error rates[1]. A repeated measures ANOVA on reaction time showed a main effect of similarity $F(1, 20) = 65.89$, $p < .001$, suggesting that the participants were faster when the relevant dimensions of the prime and probe were the same (543 ms) compared with when they were different (727 ms). More important, there was also a significant compatibility effect $F(2, 40) = 19.94$, $p < .001$ and a Similarity x Compatibility interaction $F(2, 40) = 4.21$, $p < .05$. Tukey's honestly significant difference tests indicated that on the trials in which the relevant dimensions of the prime and probe were the same (the *same* trials), the participants were faster in the neutral condition (529 ms) than in both the compatible and incompatible conditions (551 ms and 549 ms, respectively), with no significant difference between the latter two. Conversely, on the trials in which the relevant dimensions of the prime and probe were different (the *different* trials), the participants' reaction times did not differ significantly between the neutral and compatible conditions (700 ms and 726 ms, respectively). However, they were shorter in both of those conditions than in the incompatible condition (756 ms).

An ANOVA on accuracy revealed a significant main effect of similarity $F(1, 20) = 29.56$, $p < .001$, suggesting that the participants made fewer mistakes on the same trials (3.7% error) than on the different ones (9.0% error). No other effects approached significance, and there was no indication of a speed-accuracy tradeoff.

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Insert Table 1 about here

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Consistent with previous findings (e.g., Remington & Folk, 2001; Yang & Kim, 2003), the participants showed a positive priming effect, indicating that they encoded the relevant dimension of the prime even though it was not a target. In addition, they demonstrated a response compatibility effect. The fact that their reaction times were influenced by the response compatibility between the two prime dimensions suggests that the irrelevant prime dimension was processed.

How can one explain the compatibility effect? One possible interpretation is along the lines of feature-response integration proposed by Hommel (1998), which was based on the concept of an “object file” developed by Kahneman and Treisman (1984; Kahneman, Treisman, & Gibbs, 1992). According to Kahneman and Treisman, the visual system creates a temporary object file when it encounters an object. An object file is an episodic memory trace that stores information about the various relationships between the individual features of an object. Attention to an object triggers an automatic process of reviewing. In the case of two stimuli (S1 and S2) appearing in close temporal proximity, upon seeing S2, the reviewing process results in either the creation of a new object file or the updating of a pre-existing one. The latter occurs when specific feature conjunctions observed in S1 are largely preserved in S2, leading to the perception that S1 and S2 are different instances of the same object. Otherwise, S2 will be identified as a different object. Because creating a new object file requires more mental resources than updating an existing one does, responses to S2 will be facilitated if similar feature conjunctions are present in both stimuli.

More recently, Hommel and his colleagues (Hommel, 1998; Hommel & Colzato, 2004) extended the concept of an object file to include in it the relations between stimulus features and their associated responses. Hommel (1998) coined the term “event file” to emphasize the binding between a feature and the action performed on it. He proposed that the co-occurrence of a feature and a response would spontaneously cause the two to bind. Once they were bound, the activation of one would result in the priming of the other. This leads to the prediction that when S1 and S2 are shown in succession, responses to S2 will be facilitated if the same feature-response binding exists in both stimuli. Furthermore, because resolving the conflict induced by a previous binding is a time-consuming process, a partial match in the bindings between S1 and S2 will impair participants’ performance to S2 relative to a complete mismatch between the two stimuli.

With respect to the present experiment, the compatibility effect on the different trials can be explained in the following way. To visualize it, consider a trial in which the task was color identification and the probe was a green vertical bar. In the compatible condition, the prime would be a red bar with a left orientation. If *red* was associated with one response (R1) and *green* with another (R2), the feature-response binding in the prime would completely mismatch that in the probe, because neither of the two features in the prime, i.e., *red* and *left*, was associated with R2. In the neutral condition, the prime would be a red, horizontal bar. Again, there would be a complete mismatch in the bindings between the prime and probe. Finally, in the incompatible condition, the prime would be a red bar with a right orientation. Because R2 would be linked to both *right* in the prime and *green* in the probe, there would be partial match in the bindings between the prime and probe. Given that a partial match would delay the response to the probe relative to a complete mismatch, reaction times should be longer in the incompatible condition than in either the compatible or the neutral condition. As the data from Table 1 show, this is exactly what the experiment found. The participants were faster in the compatible and neutral conditions than in the incompatible condition.

Surprisingly, the participants showed a different pattern of data on the same trials. Unlike the *different* trials in which a significant compatibility effect was found between the compatible and incompatible conditions, reaction times were comparable between the two conditions on the *same* trials. This result is apparently inconsistent with the feature-response binding described above. How can one account for this discrepancy?

In accord with other researchers, let us assume that perception proceeds from relevant to irrelevant information (Lavie & Tsal, 1994), and that it self-terminates when the representation of a target becomes available (Treisman & Gelade, 1980). Given these assumptions, it is possible that the activation of the code representing the task-relevant dimension also precedes that of the task-irrelevant dimension. Furthermore, the degree of encoding an irrelevant dimension may depend on the processing efficiency of the target. In the present experiment, the positive priming between the relevant dimensions of the prime and probe on the same trials might have allowed the participants to acquire the representation of the probe relatively quickly. This in turn could have led to an early termination of the processing of the prime, resulting in comparable reaction times between the compatible and incompatible conditions. Alternatively, the participants might have processed the irrelevant prime dimension, but the quick response on the same trials might have prevented the result of processing from being linked to the response (A. Cohen, personal communication, April 2004). The fact that the participants in Experiment 1 were substantially slower on the *different* trials than on the *same* ones is consistent with either account.

Another interesting aspect of the data regarding the same trials concerns the shorter reaction times in the neutral condition than in either the compatible or incompatible conditions. This suggests that even though there was no behavioral evidence that the irrelevant prime dimension was identified, some degree of processing had occurred: It was categorized as being response relevant or irrelevant. Previous research on stimulus categorization and stimulus identification has shown that categorization is likely to be feature based (e.g., Duncan, 1983; Krueger, 1984) and may not need focal attention (e.g., Paquet & Merikle, 1988). More important, it can occur before stimulus identification (e.g., Brand, 1971; Gleitman & Jonides, 1976; Ingling, 1972; Jonides & Gleitman, 1976; Rabbitt, 1983). For example, Brand (1971) reported that her participants were faster to respond to a number among letter distractors than to a letter among other letter distractors, or vice versa, suggesting that it took less time to classify an item as a letter or a digit than to identify it as a specific letter or digit. Similar results were observed by Jonides and Gleitman (1976). Their participants searched for one of two pre-specified digit targets (e.g., *2* or *4*) among letter distractors. In one condition, all the elements on the target-absent trials were letters. This allowed the participants to perform a between-categories search for a digit without concerning its specific identity. In another condition, a non-target digit (e.g., *3*) was presented together with the letter distractors on half of the target-absent trials. Thus, the participants could not respond correctly unless they identified the digit first. Not surprisingly, reaction times were shorter in the first than in the second condition. If response latencies can be used as an index to indicate task difficulty, these results are consistent with the notion that categorization is easier than identification. In terms of the present experiment, the finding that the participants were faster on the *same* than no the *different* trials raised the possibility that the degree of processing of the irrelevant prime dimension might depend on the amount of time the participants had to process the prime. This hypothesis was tested in Experiments 5 and 6.

As was described earlier, Remington and Folk (2001) did not find evidence for the selection of an irrelevant feature dimension when the object was not a target. Although the many methodological differences between Experiment 1 and the Remington and Folk study made it difficult to know the exact cause of their dissimilar results, one potentially important difference might be the specific feature dimension to which the participants paid attention. Whereas it was likely that the participants in the Remington and Folk study were attending to the location of the critical object before its onset, Experiment 1 was designed to induce them to focus attention to the color or orientation of the prime on each trial. In light of the many differences regarding the role of location and the role of an object feature in selective attention (see Lamy & Tsal, 2001, for a review), it is possible that the discrepancy in results between the two studies was due to a difference in the specific feature dimension of an object that has received attention (see the General Discussion section for more detailed discussion on it).

It is important to note that even though location was not related to any specific responses in Experiment 1, this does not imply that it was unimportant[2]. The fact that the irrelevant prime dimension belonged to the same object as the attended relevant dimension and thereby occupied the same spatial location as the latter may be a crucial factor in its selection. This is consistent with the recent finding of Feintuch and Cohen (2002), who reported that an irrelevant feature affected performance only when it belonged to the same object as the relevant feature or when the two were perceptually grouped. Together, these results suggest that the processing of a task-irrelevant feature may occur only when it is within a participant's attentional focus.

A second potentially important difference between Experiment 1 and the Remington and Folk (2001) study concerns the way the stimuli were presented. Whereas the prime and probe were displayed in succession in the present experiment, the critical non-target object was shown in the same display as the target in Remington and Folk. This difference may influence the amount of attentional resources available for the non-target object. Because objects compete for attention (Chen, 2000; Kahneman et al., 1983), the presence of other stimuli, in particular that of a target, in the same display as the critical non-target object would limit the amount of attention it could receive. This may in turn lead to differential levels of processing of the irrelevant feature dimension in the two experiments.

One way to determine whether attention to location versus an object feature is an important factor in the obtained results is to induce participants to attend to location on some trials and to an object feature on others. If it is an important factor, one should observe differential levels of processing of the irrelevant prime dimension between the two types of trials. Otherwise, no significant differences should be found. Experiment 2 tested this hypothesis.

## Experiment 2

Experiment 2 examined whether participants would show differential degrees of processing of the irrelevant prime dimension when the task was to respond either to the probe's location (up or down) or to its identity (*T* or *V*). Assuming that the participants would attend to the task-relevant dimension on a given trial, the critical question was whether they would demonstrate the response compatibility effect in the identity task, but not in the location task.

### *Method*

*Participants*. Nineteen new participants from the same participant pool took part in the experiment.

*Apparatus and Stimuli*. The apparatus was the same as that in Experiment 1. Several changes were made to the stimuli. First, the response cue was either a vertical two-headed arrow (↕) that subtended 1.92° of visual angle or a string of three letters (*ABC*) in 30-point Times font. Second, instead of colored lines, the prime and probe were made of white letters. The prime was equally likely to be the letter *T* or *V* presented in 60-point Geneva font, with its center at one of the four vertices of a $10.51^0$ x $2.87^0$ imaginary rectangle. The probe differed from the prime in that both its identity and location depended on the specific response cue on a given trial. On location-relevant trials, it was the letter *F*, and it could appear at one of the four locations described above. On identity-relevant trials, it was either the letter *T* or *V* at one of two locations: $5.26^0$ to the left or to the right of the center. The participants pressed the < key when the response was *up* or *T*, and the > key when it was *down* or *V*.

*Design and Procedure*. The design and procedure were similar to those in Experiment 1 except that the neutral condition was not used. Thus, for both the identity and location tasks, there were four conditions: same-compatible, same-incompatible, different-compatible, and different-incompatible. As before, the relevant dimensions of the prime and probe were the same on two-thirds of the trials, and they were different on the remaining ones. The two dimensions of the prime were equally likely to be compatible or incompatible. All the other aspects of the experiment were identical to those of Experiment 1.

### *Results and Discussion*

The results are shown in Table 2. A repeated-measures ANOVA on reaction times with task, similarity, and compatibility as factors revealed a main effect of similarity $F(1, 18) = 148.11$, $p < .001$, replicating the result of Experiment 1 that the participants were faster when the relevant dimensions of the prime and probe were the same (665 ms) than when they were different (840 ms). There was also a three-way interaction among task, similarity, and compatibility $F(1, 18) = 9.24$, $p < .01$. To clarify the interaction, I conducted two separate ANOVAs. For the identity task, there was a main effect of Similarity as well as a Similarity x Compatibility interaction $F(1, 18) = 104.80$, $p < .001$, and $F(1, 18) = 5.84$, $p < .05$, respectively. Planned comparisons indicated shorter reaction times in the compatible condition (826 ms) than in the incompatible condition (868 ms) when the relevant dimensions of the prime and probe were different $t(18) = 2.26$, $p < .05$. However, when they were the same, no significant difference was found between the two conditions 656 ms and 653 ms for the compatible and incompatible conditions, respectively, $t(18) = -0.44$, *ns*. For the location task, an ANOVA yielded a significant main effect of similarity 674 ms and 833 ms for the *same* and *different* trials, respectively, $F(1, 18) = 94.09$, $p < .001$ and a two-way interaction between similarity and compatibility $F(1, 18) = 5.62$, $p < .03$. At face value, the interaction might appear inconsistent with the hypothesis. However, inspection of the data revealed that the interaction was caused by a numerical decrease in reaction time from the compatible to incompatible conditions on the different trials together with a numerical increase in reaction times from the compatible to incompatible conditions on the same trials. Thus, the data pattern was entirely different from that in the identity task. Furthermore, planned comparisons confirmed that there was no significant compatibility effect on either the same or different trials $t(18) = 1.18$, *ns*., and $t(18) = -1.43$, *ns*., respectively, suggesting no reliable compatibility effect on either type of trials.

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Insert Table 2 about here

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Similar analyses were conducted on the accuracy data. A main effect of task was found $F(1, 18) = 6.07$, $p < .05$, indicating that the participants were more accurate in the letter task (4.8% error) than in the location task (7.5% error) $F(1, 18) = 21.61$, $p < .001$. In addition, there were a main effect of similarity $F(1, 18) = 21.61$, $p < .001$ and a Similarity x Compatibility interaction $F(1, 18) = 6.32$, $p < .05$. In agreement with the reaction times data, the participants were more accurate on the *same* (3.9% error) than *different* trials (8.5% error). Moreover, the magnitude of the compatibility effect was larger on the *different* trials (2.1% error) than on the *same* ones (-0.3% error). Because the three-way interaction did not reach significance, no further analyses were conducted.

The results suggest that the effect of attention on selection differs as a function of the task-relevant dimension. More specifically, these results support the notion that the particular feature dimension that received attention is an important factor in the degree of processing of the irrelevant prime dimension. In the location task, the processing of the irrelevant prime dimension was negligible. If one assumes that the participants' attention was directed to location on location-relevant trials, this result was consistent with Remington and Folk's (2001) finding, whose participants also showed no evidence of encoding the irrelevant dimension of an attended non-target object. Given the many methodological differences between the two experiments, the similarity in data was remarkable. Recall that in Remington and Folk (2001), the researchers used an exogenous cue (i.e., a color singleton) to direct the participants' attention to a specific location, and the participants then performed a letter or an orientation discrimination task. In contrast, in Experiment 2, an endogenous cue (i.e., a centrally located arrow) was used to direct the participants' attention to the relevant dimension, and the participants then responded to the location of the probe. However, despite these and other differences detailed earlier, the results of the experiments were very similar. Thus, even though there are inherent difficulties in interpreting null results, the fact that the outcomes of the two experiments were comparable strengthens the conclusion that when attention is paid to the location of a non-target object, it does not automatically select other object features that belong to the same object.

Contrary to the null results in the location task, the participants demonstrated a response compatibility effect in the identity task, presumably because their attention was directed to the shape of the prime. Furthermore, as in Experiment 1, the effect was obtained only on the different trials. Because the averaged reaction times in the location and identity tasks were comparable, the differential patterns of data between the two tasks could not be due to a difference in the processing efficiency of the probe. Instead, these data provide converging evidence to the findings of Experiment 1 that attending to a non-location feature of the prime can lead to the selection of its irrelevant dimension and that the processing efficiency of the probe may modulate the extent of selection of the prime.

Previous experiments have shown that within an event file the strength of the bindings between the various features and between features and their associated responses may be sensitive to task demands (e.g., Gordon & Irwin, 1996; Henderson, 1994; Hommel, 1998). For example, Hommel (1998) reported that the binding between location and form affected performance only when form was task-relevant ans not when color was task-relevant. Likewise, the binding between location and color influenced performance only when color was task-relevant and not when form was task-relevant. The fact that the compatibility effect differed as a function of the task in the present experiment suggests that the strength of the binding may also be influenced by the specific task-relevant feature: Whereas location might bind readily with an object feature when the latter was an attended dimension, an object feature might not bind spontaneously with location in all circumstances. Attending to location versus an object feature could differentially influence the degree of the activation of other features that pertain to the same object.

Although evidence for processing the irrelevant prime dimension was clearly present in Experiments 1 and 2, one might argue that this could be due to the participants' deliberate encoding rather than involuntary processing of the prime. Because the relevant dimensions of the prime and probe were the same on two-thirds of the trials in both experiments, the prime was predictive of the probe's response on most of the trials, which in turn might have prompted the participants to encode the prime intentionally. Had this been the case, it would have been inappropriate to construe the prime as an irrelevant distractor.

The next experiment distinguished the deliberate-encoding account from the involuntary-processing one by making the prime uninformative. Imagine that participants perform the same task as in Experiment 1 except that the prime is not predictive of the probe. Because the prime does not carry any useful information, the participants would have no apparent reason to encode it intentionally. The deliberate-encoding account would therefore predict no response compatibility effect in the new experiment. In contrast, because the involuntary-processing account does not assume strategic control on the part of the participants, it would still predict the selection of the irrelevant prime dimension.

## Experiment 3

Experiment 3 was essentially a replication of Experiment 1 but with two important modifications. The first modification concerns the locations of the prime and probe. They were presented either above or below the center of the screen instead of to the left or right of it. This change in location was to eliminate the possible influence of the Simon effect (Simon, Hinrichs, & Craft, 1970) that might have been present in Experiment 1. The Simon effect refers to the phenomenon that participants are typically faster when the location of a stimulus corresponds with the location of a response key rather than when the two are unrelated. In Experiment 1, the locations of the prime and probe coincided with the horizontal arrangement of the response keys. Although the Simon effect would have averaged out in the final results and should therefore not influence the interpretation of the results, its removal might increase the sensitivity of the new experiment. The second modification involves the prime, which was made uninformative so that its relevant dimension was equally likely to be the same as or different from the relevant dimension of the probe. If the selection of the irrelevant prime dimension observed in Experiment 1 was caused by the participants' attempt to encode the prime intentionally, no response compatibility effect should be found in this experiment. Otherwise, the participants should still demonstrate differential reaction times as a function of the response compatibility between the relevant and irrelevant prime dimensions.

*Method*

*Participants*. Fifteen naive participants were recruited from the same participant pool.

*Apparatus and Stimuli*. The apparatus and stimuli were the same as those used in Experiment 1. However, the prime and probe were presented at $1.43^0$ above or below the center of the screen.

*Design and Procedure*. The design and procedure of Experiment 3 were identical to Experiment 1 with the exception that the prime was uninformative. The relevant dimensions of the prime and probe were same on half the trials and different on the rest. The participants were explicitly told that the prime contained no useful information regarding the correct response to the target.

*Results and Discussion*

Table 3 shows the mean reaction times and the accuracy data. A repeated-measures ANOVA revealed that the participants were both faster and more accurate when the relevant dimensions of the prime and probe were the same (611 ms with 5.1% error) than when they were different 705 ms with 8.8% error, $F(1, 14) = 85.59$, $p < .001$, and $F(1, 14) = 11.11$, $p < .01$, for reaction times and accuracy, respectively. The reaction times data also showed a significant main effect of compatibility $F(2, 14) = 17.93$, $p < .001$. The Similarity x Compatibility interaction did not reach statistical significance, due to a numerical increase in reaction time from the compatible to incompatible conditions on the same trials. However, additional analyses were performed on the same and different trials separately, because from a theoretical perspective, it was important to determine whether the participants demonstrated similar patterns of data in Experiment 3 as in Experiment 1 with respect to the magnitude of the compatibility effect on the same versus different trials. As before, Tukey's HSD tests were conducted because they are relatively conservative. The results revealed that on the same trials there was no significant difference between the compatible and incompatible conditions (613 ms and 630 ms, respectively), but both were slower than the neutral condition (590 ms). However, on the different trials the reaction times were longer in the incompatible condition (725 ms) than in the compatible or neutral conditions (694 ms and 697 ms, respectively), with no significant difference between the latter two.

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Insert Table 3 about here

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The central focus of Experiment 3 was to determine whether the processing of the irrelevant prime dimension would occur when the prime was uninformative. The finding that the participants showed a significant response compatibility effect in addition to a significant similarity effect indicates that both the relevant and irrelevant prime dimensions were processed. Moreover, the pattern of data regarding the same versus different trials was similar to that in Experiment 1. In both experiments, the participants appeared to classify the irrelevant prime dimension as being response relevant or irrelevant on the same trials. On the contrary, on the different trials their response latencies were significantly shorter in the compatible than in the incompatible condition, suggesting that the irrelevant prime dimension was identified.

One might argue that the results of Experiment 3 could not completely rule out the deliberate-encoding account as a potential factor that contributed to the response compatibility effect. Perhaps the prime and probe both had abrupt onsets, or the participants simply got into the habit of trying to encode everything that appeared on the screen. Although these possibilities exist, they are not very likely. Logically, for participants to engage in deliberate encoding of an experimental stimulus, they need to have incentives. The stimulus either has to be a target or has to be related to a target in some way. Neither of these conditions existed in Experiment 3. Furthermore, the participants were explicitly informed in the instruction that the prime was not predictive of the correct response, and that they should ignore it. Inspection of the existing literature also indicates no evidence that a distractor with an abrupt onset would induce participants to engage in purposeful encoding. If anything, available evidence suggests the opposite – that processing involving an abrupt onset object is involuntary rather than intentional (see Yantis & Egeth, 1999, for a review)[3].

Although the results of Experiment 3 made it unlikely that the primary cause of the response compatibility effect observed in the previous experiments was participants' deliberate encoding of the prime, it was still desirable to conduct a further experiment that would involve the manipulation of a location task versus a non-location task. A successful replication of Experiment 2 with an uninformative prime would increase our confidence that the nature of the specific feature dimension that receives attention plays a key role in the effects of attention on selection.

## Experiment 4

Experiment 4 was identical to Experiment 2 except that the prime was uninformative. As in Experiment 2, participants responded to either the location or the identity of the probe as indicated by the response cue. On the basis of the results of Experiments 2 and 3, it was predicted that the participants would show the response compatibility effect in the identity task but not in the location task despite the fact that the prime was not predictive of the probe.

*Method*

*Participants*. Sixteen participants from the same participant pool took part in the experiment.

*Apparatus and Stimuli*. Both the apparatus and stimuli were identical to those used in Experiment 2.

*Design and Procedure*. These were the same as those in Experiment 2 except that the prime was uninformative.

*Results and Discussion*

Table 4 shows the mean reaction times and the accuracy data. One participant's data were excluded from analyses because of her high error rate, which exceeded 43% in one condition. A three-way ANOVA on reaction times found a main effect of similarity $F(1, 14) = 32.86$, $p < .001$, a two-way interaction between task and similarity $F(1, 14) = 5.51$, $p < .05$, and a three-way interaction among task, similarity, and compatibility $F(1, 14) = 11.66$, $p < .01$. As in the previous three experiments, the participants were faster on the same trials (605 ms) in comparison to the different ones (706 ms), demonstrating the similarity effect. In addition, the effect was larger in the identity task (121 ms) than in the location task (81.5 ms). To interpret the three-way interaction, I performed two separate ANOVAs. For the identity task, all effects were significant for similarity: $F(1, 14) = 44.41$, $p < .001$; for compatibility: $F(1, 14) = 6.46$, $p < .05$, and for a Similarity x

Compatibility interaction: $F(1, 14) = 11.64$, $p < .01$. Consistent with the results in Experiment 2, planned comparisons indicated that whereas the participants were faster in the compatible (687 ms) than in the incompatible (732 ms) condition on the *different* trials $t(14) = 3.50$, $p < .01$, there was no significant difference between the two conditions (589 ms and 588 ms for the compatible and incompatible conditions, respectively) on the *same* trials, $t(14) = -0.14$, *ns*. For the location task, only the main effect of similarity reached significance, $F(1, 14) = 15.19$, $p < .01$. No other effects were observed.

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Insert Table 4 about here

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An ANOVA on the accuracy data yielded four significant effects: the main effects of similarity and compatibility $F(1, 14) = 12.15$, $p < .01$, and $F(1, 14) = 7.41$, $p < .05$, respectively, a two-way interaction between similarity and compatibility $F(1, 14) = 15.15$, $p < .01$, and a three-way interaction among task, similarity, and compatibility $F(1, 14) = 5.74$, $p < .05$. Further analyses revealed that for the location task, only the main effect of similarity was significant $F(1, 14) = 5.12$, $p < .05$, suggesting that the participants were more accurate when the relevant dimensions were the same (5.3% error) than when they were different (7.4% error). For the identity task, the participants were more accurate on the same trials (3.9% error) than on the different ones (6.0% error), $F(1, 14) = 9.91$, $p < .01$. Moreover, there was a significant Similarity x Compatibility interaction $F(1, 14) = 24.03$, $p < .001$. Planned comparisons indicated that although the participants made fewer mistakes in the compatible condition (3.4% error) than in the incompatible condition (8.6% error) on the different trials $t(14) = 3.87$, $p <$

.01, they showed a reversed compatibility effect on the same trials $t(14) = -4.07$, $p < .01$, with a higher error rate in the compatible (5.5% error) than in the incompatible (2.2% error) condition.

Except for the last aspect of the data, Experiment 4 replicated the results of Experiment 2. Whereas the irrelevant prime dimension was processed in the identity task, there was no evidence that similar processing occurred in the location task. These results confirmed the existence of a processing asymmetry between location and non-location trials. They also provided converging evidence to the findings of Experiment 3 that deliberate encoding of the prime was unlikely to be the primary cause for the results of Experiments 1 and 2. As for the curious finding regarding the reversal of the compatibility effect in the accuracy data, there appeared to be no apparent reason why this should be the case. Further experiments are required to determine the cause of this result.

So far, the picture that emerged from Experiments 1-4 seems to be a complex one. With respect to a non-target object, attention entailed selection when two conditions were met: The attended feature was an object feature such as color, orientation, or shape, and the relevant dimensions of the prime and probe were different. In contrast, when the attended feature was an object’s location or when the relevant dimensions of the prime and probe were the same, attention and selection were dissociated. As was suggested earlier, because the participants’ reaction times was substantially shorter on the *same* relative to *different* trials, this raised the possibility that the degree of selection of an attended non-target object might depend on the processing efficiency of the target, which in turn could be related to the processing time available for the prime. Experiments 5 and 6 tested this hypothesis empirically.

## Experiment 5

Experiment 5 had two goals. The primary goal was to investigate whether the selection of the irrelevant prime dimension would be modulated by the participants' overall reaction times in a given task. By varying the eccentricities of the prime and probe in addition to the previous manipulations of similarity and compatibility, it was hoped that participants would show differential reaction times between the conditions because of the longer latencies with increasing eccentricity (e.g., Hughes & Zimba, 1985; Payne, 1966; Raines, 1964; Zimba & Hughes, 1987). This might in turn result in different levels of processing of the irrelevant prime dimension. The second goal was to provide converging evidence to the results of two recent experiments in which processing of the irrelevant prime features occurred despite the fact that they were not physically identical to the reporting features of the experiment (Chen, 2003a). In all four experiments presented so far, the specific features that constituted the irrelevant prime dimension were identical to the features that were required to be reported for the probe. In other words, it was unclear whether identical physical appearance was necessary for the selection of an attended non-target object to occur. To investigate this issue, I conducted two experiments in which participants responded to the identity or the orientation of the probe as indicated by the response cue. Specifically, whereas the probe was an uppercase *T* or *V* with a $30^0$ left or right orientation, the corresponding prime was a lowercase *t* or *v* with a $60^0$ orientation. Despite these differences in stimuli, the results of the experiments were remarkably similar to the previous four experiments reported here. The participants showed the response compatibility effect when the relevant dimensions of the prime and probe were different, and the effect persisted regardless of whether the prime was informative or uninformative.

Experiment 5 used two groups of participants. They saw essentially identical stimulus displays except that the eccentricity between the prime and probe was relatively small for one group (the *near* group) and large for the other group (the *far* group). Assuming that the participants in the *near* group would be faster than their counterparts in the *far* group, it was of special interest whether the two groups would also differ in the degree of processing of the irrelevant prime dimension.

*Method*

*Participants*. Forty-eight participants took part in the experiment. None were aware of the purpose of the experiments or participated in the previous experiments.

*Apparatus and Stimuli*. The apparatus was the same as that in Experiment 1. All of the stimuli were letters. The response cue, displayed at the center of the screen, was either a black letter *L* or *O* written in 60-point Geneva font, with *L* referring to letter identity and *O* to orientation. Both the prime and probe were white. The prime was a lowercase *t* or a *v* with a $60^0$ left or right tilt on two-thirds of the trials. On the remaining trials, its identity and orientation depended on the specific response cue on a given trial. When the task was identity discrimination, it was a *t* or a *v* with a horizontal orientation. When the task was orientation discrimination, it was an *i* with a $60^0$ left or right tilt. The probe was a vertical, uppercase letter *T* or *L* on identity-relevant trials, or an *F* with a $30^0$

left or right tilt on orientation-relevant trials. The prime and probe were displayed directly above or below the center of the screen, with their separation being either $4.78^0$ (for the near group) or $12.42^0$ (for the far group). The participants pressed the < key when the response was *T* or *left*, and the > key when the response was *V* or *right*.

*Design and Procedure*. The experiment was a mixed design, with eccentricity as the between-participants variable and similarity and compatibility as the within-participants variables. Half of the participants were in the *near* group, and the other half in the *far* group. As in Experiments 3 and 4, the prime was uninformative. All the other aspects of the experiment were identical to those of Experiment 1.

*Results and Discussion*

The mean reaction times and error rates are shown in Table 5. The data from two participants who had error rates that exceeded 20% in multiples conditions were not included in the analyses. A three-way ANOVA on reaction times showed a main effect of group $F(1, 44) = 5.95$, $p < .05$, suggesting that the participants in the near group were faster than those in the far group (567 ms and 615 ms for the near and far groups, respectively). The main effect of similarity was also significant $F(1, 44) = 46.83$, $p < .001$. As in the previous experiments, the participants were faster on the same trials (578 ms) than on different ones (604 ms). In addition, there was a main effect of compatibility $F(2, 44) = 13.74$, $p < .001$ and a Group x Compatibility interaction $F(2, 88) = 3.61$, $p < .05$. The latter result indicated that the compatibility effect was greater in the far than in the near group. Visual inspection of the data revealed that the differences among the various experimental conditions in the near group were negligible (571 ms, 573 ms, and 566 ms for the compatible, incompatible, and neutral trials, respectively).

To determine that the main effect of compatibility was driven primarily by the differential reaction times in the far group rather than in the near group, I conducted two separate ANOVAs even though the three-way interaction among group, similarity, and compatibility did not reach statistical significance. For the near group, the analysis revealed only one significant effect of similarity $F(1, 22) = 54.44$, $p < .001$, indicating shorter reaction times on the same trials (551 ms) than on different ones (583 ms). For the far group, the results found a significant similarity effect 606 ms and 624 ms for the same and different trials, respectively, $F(1, 22) = 9.50$, $p < .01$ and a response compatibility effect $F(1, 22) = 15.51$, $p < .001$, but the interaction between similarity and compatibility was nonsignificant $F(2, 44) = 3.03$, $p < .06$. To ascertain that the pattern of the compatibility effect differed between the same and different trials as was found in the previous experiments, I carried out planned comparisons. The results showed that on the same trials the reaction times were shorter in the neutral condition (594 ms) than in both the compatible condition (611 ms) and the incompatible condition 612 ms, $t(22) = 3.38$, $p < .01$ and $t(22) = 2.70$, $p < .02$, respectively, with no significant difference between the latter two $t(22) = -0.02$, ns. On the different trials, the participants were faster in the neutral condition (613 ms) than in the compatible condition (622 ms) and the incompatible one 637 ms, $t(22) = 2.43$, $p < .05$, and $t(22) = 4.98$, $p < .01$, respectively. More important, the difference between the compatible and incompatible conditions was also significant $t(22) = 3.28$, $p < .01$.

Insert Table 5 about here

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Similar analyses were conducted on the accuracy data. There was a main effect of similarity $F(1, 44) = 5.61$, $p < .05$, suggesting that the participants made fewer mistakes on the same trials (4.3% error) than on the different ones (5.0% error). No other effects reached significance, and no speed-accuracy tradeoff was found.

The results support the hypothesis that the processing efficiency of the target is an important factor in determining the degree of selection of an attended non-target object. In the *far* group in which the overall reaction times were relatively long (615 ms) compared with those in the *near* group (567 ms), the participants showed the same pattern of data as that in Experiments 1 and 3. Despite the differences in physical appearance between the specific features of the prime and the reporting features of the probe, the participants again demonstrated evidence of processing the irrelevant prime dimension. These results replicated my previous findings (Chen, 2003a), and they suggest that the processing of the irrelevant prime dimension did not require identical stimulus features between the prime and probe.

Contrary to their counterparts in the far group, the participants in the near group did not show behavioral evidence of processing the irrelevant prime dimension. There was no indication that it was either identified or categorized. Given that the only differences between the near and far groups were the eccentricities of the prime and probe and their associated acuities, it seems reasonable to infer that these factors affected the participants' overall response latencies to the probe, which in turn influenced the selection of the irrelevant prime dimension.

A possible objection to the above conclusion is that it was based partly on the retention of the null hypothesis. Because the absence of a compatibility effect in the near condition could also be attributed to a lack of statistical power, it would be desirable to conduct a further experiment to obtain converging evidence. If the processing asymmetry observed in the previous experiments was indeed due to the availability of the probe response before the irrelevant prime dimension could be identified, delaying the onset of the probe should increase the processing time available for the prime, which in turn would eliminate the differential compatibility effects between the same and different trials[4].

## Experiment 6

Experiment 6 was similar to Experiment 3, with the major difference being the insertion of an interstimulus interval (ISI) between the prime and probe. By delaying the onset of the probe to allow participants to have more time to process the prime, it was predicted that they would show comparable compatibility effects on both the same and different trials.

### *Method*

*Participants*. Nineteen new participants were recruited from the same participant pool.

*Apparatus and Stimuli*. They were the same as those in Experiment 3.

*Design and Procedure*. The design differed from that of Experiment 3 in two ways: the elimination of the neutral condition and the insertion of an ISI of either 60 ms (the short ISI) or 240 ms (the long ISI) between the offset of the prime and the onset of the probe. The value of the short ISI was chosen to approximate the group difference in Experiment 5. Recall that the participants in the near group did not show evidence of processing the irrelevant prime dimension, and the average of their response latencies was about 50 ms shorter than the participants in the far group. Although this by no means suggests that 50 ms is some magical number, if inducing the participants to delay the processing of the probe for about 50 ms could lead to the response compatibility effect between the relevant and irrelevant dimensions of the prime on both the same and different trials, this would provide converging evidence to the findings of Experiment 5. The value of the long ISI was chosen to investigate the decay of the response compatibility effect. Positive priming between the relevant dimensions of the prime and probe is known to diminish overtime (e.g., Henderson, 1994; Hommel, 1998). However, little is known about the duration of the effect of an attended irrelevant dimension. Thus, Experiment 6 used a 2 x 2 x 2 within-participants design, with ISI (short or long), prime-probe similarity (same or different), and intra-prime compatibility (compatible or incompatible) as the principal manipulations.

The participants were explicitly instructed to keep their eyes fixated at the center of the screen throughout the duration of a trial. This was to discourage them from overt orientation to the stimuli, especially on the long ISI trials. They were told that because the prime and the target did not occur at the same location, they would find it more efficient to keep their eyes still during a trial. Moreover, their eye movements were monitored during the practice session by either me or my research assistant. If one was detected, the participant would be reminded of the fixation requirement. It was hoped that these measures would keep overt orientation to a minimum even though it might not be eliminated completely.

*Results and Discussion*

Table 6 lists the mean reaction times and accuracy data. One participant's data were not included because of his high error rates, which were averaged over 40% for the short ISI trials. A repeated measures ANOVA on reaction times indicated three main effects and a two-way interaction[5]. The participants were slower when the ISI was short (617 ms) compared with when it was long (560 ms) $F(1, 17) = 8.50$, $p < .01$[6]. As before, their reaction times were shorter when the relevant dimensions of the prime and probe were the same (549 ms) rather than when they were different (629 ms) $F(1, 17) = 73.77$, $p < .001$, and when the two dimensions of the prime were compatible (583 ms) than when they were incompatible (595 ms) $F(1, 17) = 6.67$, $p < .05$. The interaction between ISI and similarity was also significant $F(1, 17) = 12.15$, $p < .01$, suggesting that the similarity effect was larger when the ISI was short (108 ms) relative to when it was long (52 ms). More importantly, there was neither a two-way interaction between similarity and compatibility $F(1, 17) <0.01$, *ns*. nor a three-way interaction among ISI, similarity, and compatibility $F(1, 17) = 0.052$, *ns*.. Visual inspection of the data revealed no indication of any trend of such interactions either.

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Insert Table 6 about here

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An ANOVA on accuracy found a main effect of similarity $F(1, 17) = 18.63$, $p < .001$ and a Similarity x Compatibility interaction $F(1, 17) = 7.58$, $p < .05$. Consistent with the reaction times data, the participants made fewer errors on the same trials (4.1% error) than on the different ones (6.6% error). Moreover, whereas there was an indication of a compatibility effect on the same trials (2.7% error), such an effect was virtually non-existent on the different trials (-0.1% error). No other effects reached significance.

Consistent with the results of Experiment 5, the participants showed evidence of processing the irrelevant prime dimension when the processing time of the prime was prolonged. Although delaying the onset of the probe for 60 ms added only a little time to the processing of the prime, it was enough to eliminate the processing asymmetry observed in the previous experiments. Furthermore, the magnitude of the compatibility effect remained comparable even when the ISI was increased to 240 ms, suggesting a relatively long-lasting effect. Taking the results of Experiments 5 and 6 together, they indicate that the processing efficiency of the probe played an important role in determining the degree of encoding of the irrelevant prime dimension in the previous experiments.

Another interesting aspect of the data is the substantial decrease in positive priming from 108 ms on the short ISI to 52 ms on the long ISI trials, suggesting that the facilitatory effect of feature priming may be rather short-lived. As mentioned before, this finding is not new. In prior research, experiments that used relatively long stimulus onset asynchronies (SOA) typically found feature priming either weak or non-existent (e.g., Hommel, 1998; Kahneman et al., 1992). On the contrary, experiments that used relative short stimulus onset asynchronies usually reported substantial priming effects (e.g., Henderson, 1994). Consistent with these previous findings, the priming effect was much larger in the short ISI condition than in the long ISI condition, even though the effect was still evident in the latter case. This suggests that the priming of individual features is subject to rapid decay.

## General Discussion

Remington and Folk (2001) pioneered the research on the relationship between attention and selection when the attended object is a non-target object. They used a spatial cuing paradigm and found a dissociation between attention and selection (Remington & Folk, 2001). Whereas attention selects all the feature dimensions of a target, it selects only the task-relevant dimension of a distractor. Using a novel approach, the present experiments have identified two factors that influence the processing of an attended non-target object: the nature of the specific feature dimension that receives attention and the processing time available for an attended non-target object[7].

In Experiments 1 and 2, when the participants' task was to make judgments regarding a non-location object feature such as color, orientation, or shape, both the relevant and irrelevant prime dimensions were processed. In contrast, when their task was to report an object's location, only the relevant prime dimension was selected. This suggests that the critical factor in determining the selection of an irrelevant dimension might not be the status of the attended object, but rather the specific feature dimension that had received attention. Experiments 3 and 4 further indicated that these results were independent of the positive association between the prime and probe. The participants showed the same patterns of data regardless of whether the prime was informative or uninformative. Experiments 5 and 6 tested the hypothesis that the selection of the irrelevant prime dimension was also modulated by the processing time the participants had for the prime. Experiment 5 varied the eccentricities of the prime and probe. Consistent with the hypothesis, only the participants in the far group, whose response latencies were significantly longer than those in the near group, demonstrated evidence for the encoding of the irrelevant prime dimension. Experiment 6 provided converging evidence to the results of Experiment 5 by eliminating the differential compatibility effects between the same and different trials when the onset of the probe was delayed. Taken together, these results suggest that the effect of attention on a non-target object is more complex than was previously understood. When attention was paid to an object feature and when the processing of the target was relatively inefficient, attention entails the selection of all the features that belong to the same object regardless of whether they are task-relevant or irrelevant. On the contrary, when the processing of the target was efficient, or when attention was focused on an object's location, there was no behavioral evidence that the participants selected the task-irrelevant features. These findings not only provide direct empirical evidence for the involuntary selection of task-irrelevant features of an attended non-target object (e.g., Duncan, 1984; Kahneman & Henik, 1981; Kahneman & Treisman, 1984), but also delineate the boundary conditions under which such selection occurs (cf: Remington & Folk, 2001).

*Attention to Location versus Attention to an Object Feature*

The processing asymmetry regarding the irrelevant prime dimension in the present experiments underlines the importance of understanding the differential effects of attention on selection as a function of the specific feature dimension that receives attention. Recall that whereas the irrelevant prime dimension was processed in the identity tasks in Experiments 2 and 4, it was not selected in the location tasks. If one assumes that the response cue at the beginning of a trial induced the participants to pay attention to the task-relevant dimension on that trial, the null results in the location tasks are consistent with the data of Remington and Folk (2001), whose participants also failed to process the irrelevant dimension of an attended non-target object. However, because significant compatibility effects were observed in the identity tasks as well as in several other experiments even though the prime was never a target, these results are inconsistent with the proposal that behavioral goals mediate the extraction of elementary object features when the object has not been selected as a target. Instead, the present results suggest that to select an irrelevant feature dimension of a non-target object, one may need to attend to a non-location object feature rather than just to its location.

Although it is debatable whether spatial location enjoys a special role in selective attention, there is ample evidence that when participants attend to a non-spatial feature of a target, they simultaneously select its location even though the latter may be task-irrelevant (see Lamy & Tsal, 2001, for a review). For example, in one experiment, Tsal and Lavie (1993) showed participants two dots followed by a pair of letters. One of the dots was colored, and depending on its color, participants were either to search for a target letter in a subsequent display or to refrain from responding. Although the selection of the dot was based solely on color, reaction times were shorter when the target appeared at the location of the colored dot relative to a different location. Tsal and Lavie (1988; 1993) also found that when participants had responded to a target defined by color or shape, and were then encouraged to report as many letters as possible, they were more likely to report the letters that were adjacent to the target rather than those that had the same color or shape as the target. Similar results were observed by Hoffman and Nelson (1981), whose participants showed increased probability to correctly identify a stimulus if it was adjacent to a target that had been successfully recognized. Finally, Kim and Cave (1995) reported shorter reaction times in detecting a stimulus that appeared at a location previously occupied by a target than at a location previously occupied by a distractor. All these findings suggest that attending to a feature of a target entails the selection of its location.

Given that many researchers have investigated the involuntary selection of location when participants are required to report an object's color or shape, it is surprising that few people have systematically examined the involuntary selection of an object feature when the task is to report location. One exception is the series of experiments conducted by Hommel (1998). Using a precue, Hommel required his participants to perform simple left or right responses (R1) to a stimulus (S1). The response was entirely independent of S1's color, form, or location. After a short delay, a second stimulus (S2) would appear, and the participants' task was to make form or color discrimination (R2) in different experiments. The most important result in terms of the present article is the finding that neither the form nor the color of S1 was selected unless it was the task-relevant dimension of S2. In other words, a location response (R1) did not automatically lead to the selection of a non-location, task-irrelevant object feature.

The finding in the present experiments that location was selected on identity relevant trials whereas identity was not selected on location relevant trials expands the realm of involuntary selection of location from a target to a distractor. It is true that the design of the present experiments prevents us from knowing whether some minimal level of processing, such as the categorization of the irrelevant prime dimension as being task related or irrelevant, would have occurred on location trials if neutral conditions had been included in Experiments 2 or 4. However, regardless of whether such processing was possible, the present experiments suggest the existence of a processing asymmetry regarding the attentional effects on selection when attention is directed to location versus an object feature.

Although the relevant prime dimension was selected in all the experiments reported here, this does not imply that such processing will occur under all circumstances. Presumably, whether a specific feature dimension will be processed or not depends on many factors, one of which may be the perceptual load involved in a task. In a recent study, Yang and Kim (2003) used a paradigm similar to that of Remington and Folk (2001), but manipulated the perceptual load of the stimulus display in addition to the status of the critical object as being a target or a distractor. They replicated the Remington and Folk's (2001) results when the perceptual load of the task was low: The participants encoded the relevant, but not the irrelevant dimension of the critical non-target object. However, when the perceptual load was high, there was no evidence that either dimension was processed.

In addition to perceptual load, the ability of a stimulus to capture attention is another factor that may influence the effect of attention on selection. Imagine that instead of using letters in Experiments 2 and 4, one employ participants' own names are used as the prime. In light of the established literature that one's own name is particularly powerful in capturing attention in a variety of paradigms (e.g., Mack & Rock, 1998; Moray, 1959), it seems likely that participants would process their own names even in location tasks. This was indeed the result of a recent experiment (Chen & Simmonds, in press), in which the prime was either the participant's personal name or the name *Piaget*. As in Experiments 2 and 4, the task was to judge the location of the probe (*up* or *down*) or its identity (one's own name or the name *Piaget*). The most interesting finding was that the participants showed evidence of processing their own name on location relevant trials even though similar processing did not occur when the irrelevant prime dimension was "Piaget". These results provide further evidence for the flexibility of the visual system, suggesting that the effect of attention on selection is the combined result of many different factors.

*The Role of Processing Time*

The relationship between processing time and selective attention is well-documented. Many studies have shown a positive correlation between the processing load of a task and the efficiency of attentional selection (e.g., Lavie, 1995; Lavie & Cox, 1997; Rees, Frith, & Lavie, 1997; but also see Chen, 2003b; Miller, 1991). For example, participants typically demonstrate less interference from incongruent distractors when the task is difficult than when it is easy (e.g., Lavie, 1995; Lavie & Cox, 1997). They also show greater negative priming when there are few rather than more distractors (e.g., Neumann & Deschepper, 1992). In addition, processing demands influence the effect of attention on duration estimation (e.g., Brown, 1985; Chen & O'Neill, 2001; Thomas & Weaver, 1975). For example, it has been reported that when participants perform a concurrent nontemporal task in addition to duration estimation, their perceived duration is longer when the nontemporal task is easy than when it is hard (e.g., Hicks, Miller, Gaes, & Bierman, 1977; Zakay, 1993).

The novel finding of the present experiments is the observation of the role of processing time in the selection of the irrelevant feature dimension of an attended non-target object. Except for Experiment 6 in which an ISI was inserted between the prime and probe, in all the other experiments the irrelevant prime dimension was identified only on the *different* trials, and not on the *same* ones. One way to account for these results is to construe the selection of the irrelevant prime dimension as a multi-stage process. Although past research suggests that categorization may not need focal attention (e.g., Paquet & Merikle, 1988), it is likely that some kind of processing threshold needs to be reached before an object feature can be categorized. If this is indeed the case, the selection of the irrelevant prime dimension may consist of a three-stage process: pre-categorization, categorization, and identification.

As was discussed earlier, a common assumption about perception is that it is a limited resource process that proceeds from relevant to irrelevant information (Lavie & Tsal, 1994) and that it self-terminates when the target representation emerges (e.g., Treisman & Gelade, 1980). If one accepts these assumptions, the results in the present experiments are consistent with the notion that the processing time available for a stimulus is an important factor in determining the degree of encoding of its irrelevant dimension. At one extreme, participants may show little evidence of its encoding. This is likely to occur when the task is easy so that the target representation becomes available while the selection of the irrelevant dimension is still at its pre-categorization stage. At the other end of the spectrum, participants may fully identify the irrelevant dimension. This will happen when the processing of the target is inefficient or when the onset of the target is delayed so that target representation does not emerge until after the irrelevant dimension is identified. When the processing of the target is neither too efficient nor too inefficient, the irrelevant dimension may be categorized but not identified. In the present experiments, it is possible that whereas the positive priming between the prime and probe on the same trials did not allow participants enough time to complete the processing of the irrelevant prime dimension before the representation of the probe became available, the delay in response on the different trials might have enabled the identification of the irrelevant prime dimension.

Processing time may be only one of a number of factors that influence the degree of processing of the irrelevant prime dimension. Because a neutral condition was not included in either Experiment 2 or 4, it is impossible to know whether categorization of the irrelevant prime dimension could have occurred in the location task. Nevertheless, given that a significant compatibility effect was found in a location task in Chen and Simmonds (in press) when the irrelevant dimension was the participant’s own name, it seems plausible that whether an irrelevant feature is categorized or identified may also depend on the amount of attention the stimulus can attract. Further experiments are needed to understand the exact role attention plays in stimulus categorization versus identification.

*Conclusion*

Theories of visual attention have assumed that attending to an object entails the selection of all its feature dimensions (e.g., Duncan, 1984; Kahneman & Henik, 1981; Kahneman & Treisman, 1984). The present experiments show that although this assumption may apply to an attended object that is itself a target, it cannot be generalized to an object that is known to be a distractor. For a non-target object, the extent of processing is a joint function of the nature of the specific feature dimension that receives attention and the processing time it has in a given task.

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Footnotes

[1]The data were pooled across the tasks. A repeated-measures analysis of variance (ANOVA) with task, similarity, and compatibility as factors found neither a significant main effect of task nor interactions involving it. Similar results were observed in Experiments 3, 5, and 6. Consequently, only the pooled data are reported. Furthermore, in all six experiments, response latencies greater than 2,000 ms were excluded. These constituted less than 2% of the total trials.

[2]I thank Asher Cohen for pointing this out.

[3]It is also unlikely that the participants might have confused the prime with the probe. In addition to the fact that the probe was always the second stimulus after the cue whereas the prime appeared immediately following the cue, the two stimuli were not physically identical. For example, in Experiments 1 and 3, whereas the prime was either red or green with a left or right tilt, the probe was vertical on the color-relevant trials and blue on the orientation-relevant trials. Similar differences in stimuli existed in the other experiments as well. The fact that the participants were highly accurate (accuracy rate greater than 93% in all the experiments) also argues against the likelihood that they might have mistaken the prime for the probe.

[4]I thank Avishai Henik for suggesting this manipulation.

[5]No order effects were found. Thus, only the pooled data were reported.

[6]Because response latencies were calculated from the onset of the probe, although reaction times were shorter when the ISI was long rather than when it was short, the participants had in fact more time to process the prime in the former case than in the latter one because of the long delay before the onset of the probe on the long ISI trials.

[7]One might argue that because the nature of the response within each experiment was defined by the probe in addition to the response cue, the participants did not have to attend to the response cue to perform the task. For example, in Experiment 2 the participants would know that a trial required a location response if the probe was an *F*, and that it required a letter identity response if the probe was a *T* or a *V*. Although the possibility of not attending to the response cue exists, it is not very likely for three reasons. First, the participants were told explicitly in the instruction to pay attention to the response cue at the beginning of each trial. They were informed that ignoring it would substantially increase their reaction time. Furthermore, their response latencies were closely monitored during the practice block. If there was any indication of a lack of attention such as prolonged reaction time on a given trial, they were immediately reminded of the attention requirement. Secondly, even if the participants chose to ignore the response cue during the experiment, the abrupt onset of the prime would capture their attention (Yantis & Jonides, 1984, 1990). Lastly, inspection of the data suggests that the participants did pay attention to the response cue or the relevant dimension of the prime, at least on the majority of the trials. Recall that the main difference between Experiments 2 and 4 was the information value of the prime. Whereas the prime was informative in Experiment 2, it was neutral in Experiment 4. If the participants had not attended to the response cue, the positive priming effect would have been comparable in the two experiments. However, the magnitude of the effect in Experiment 4 was only about half of that in Experiment 2. The positive correlation between the information value of the cue and the magnitude of the priming effect suggests that the participants had followed the instruction. A similar pattern of data could also be found in Experiments 1 and 3.

Table 1

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 1.

| | Intra-Prime Compatibility | | |
|---|---|---|---|
| Prime-Probe Similarity | Compatible | Incompatible | Neutral |
| | Reaction Times | | |
| Same | 551 (26.2) | 549 (24.6) | 529 (23.4) |
| Different | 726 (37.3) | 756 (39.3) | 700 (38.8) |
| | Error Rates | | |
| Same | 3.1 (0.5) | 4.7 (0.5) | 3.2 (0.6) |
| Different | 8.8 (1.2) | 8.7 (1.2) | 9.4 (1.2) |

Note – The standard errors shown here represent the between-subjects variability within a condition, not the within-subjects variability across conditions that is of interest in the present paper.

Table 2

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 2.

| | Task | | | |
|---|---|---|---|---|
| | Location | | Identity | |
| Prime-Probe Similarity | Compatible | Incompatible | Compatible | Incompatible |
| | Reaction Time | | | |
| Same | 667 (37.7) | 681 (37.1) | 657 (30.1) | 653 (29.4) |
| Different | 843 (29.2) | 822 (32.9) | 826 (35.0) | 868 (32.3) |
| | Error Rate | | | |
| Same | 4.5 (1.10) | 5.3 (1.15) | 3.6 (0.65) | 2.3 (0.46) |
| Different | 9.2 (1.31) | 11.1 (1.94) | 5.6 (0.91) | 7.9 (1.16) |

Table 3

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 3.

| | Intra-Prime Compatibility | | |
|---|---|---|---|
| Prime-Probe Similarity | Compatible | Incompatible | Neutral |
| | Reaction Times | | |
| Same | 613 (38.0) | 630 (38.7) | 590 (35.2) |
| Different | 694 (37.5) | 725 (41.2) | 697 (39.0) |
| | Error Rates | | |
| Same | 5.1 (1.2) | 5.4 (1.4) | 4.7 (1.0) |
| Different | 10.0 (2.3) | 8.2 (1.9) | 8.3 (1.8) |

Table 4

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 4.

| | Task | | | |
|---|---|---|---|---|
| | Location | | Identity | |
| Prime-Probe Similarity | Compatible | Incompatible | Compatible | Incompatible |
| | Reaction Time | | | |
| Same | 613 (37.9) | 628 (40.2) | 589 (31.7) | 588 (32.9) |
| Different | 704 (55.2) | 700 (50.1) | 687 (43.4) | 732 (45.8) |
| | Error Rate | | | |
| Same | 5.3 (1.48) | 5.3 (1.21) | 5.5 (1.03) | 2.2 (0.47) |
| Different | 5.9 (0.74) | 8.9 (1.44) | 3.4 (0.61) | 8.6 (1.46) |

Table 5

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 5.

A. The "near" group

| | Intra-Prime Compatibility | | |
|---|---|---|---|
| Prime-Probe Similarity | Compatible | Incompatible | Neutral |
| | Reaction Times | | |
| Same | 553 (11.9) | 554 (11.9) | 546 (12.2) |
| Different | 584 (11.3) | 585 (12.4) | 581 (12.8) |
| | Error Rates | | |
| Same | 3.8 (0.6) | 4.3 (0.9) | 3.7 (0.5) |
| Different | 5.9 (0.8) | 4.4 (0.7) | 5.2 (0.8) |

B. The "far" group

| | Intra-Prime Compatibility | | |
|---|---|---|---|
| Prime-Probe Similarity | Compatible | Incompatible | Neutral |
| | Reaction Times | | |
| Same | 611 (18.1) | 612 (17.0) | 594 (17.3) |
| Different | 622 (15.0) | 637 (16.3) | 613 (14.9) |
| | Error Rates | | |
| Same | 4.6 (0.8) | 4.9 (0.8) | 4.3 (0.8) |
| Different | 4.5 (0.8) | 5.0 (0.9) | 4.9 (0.8) |

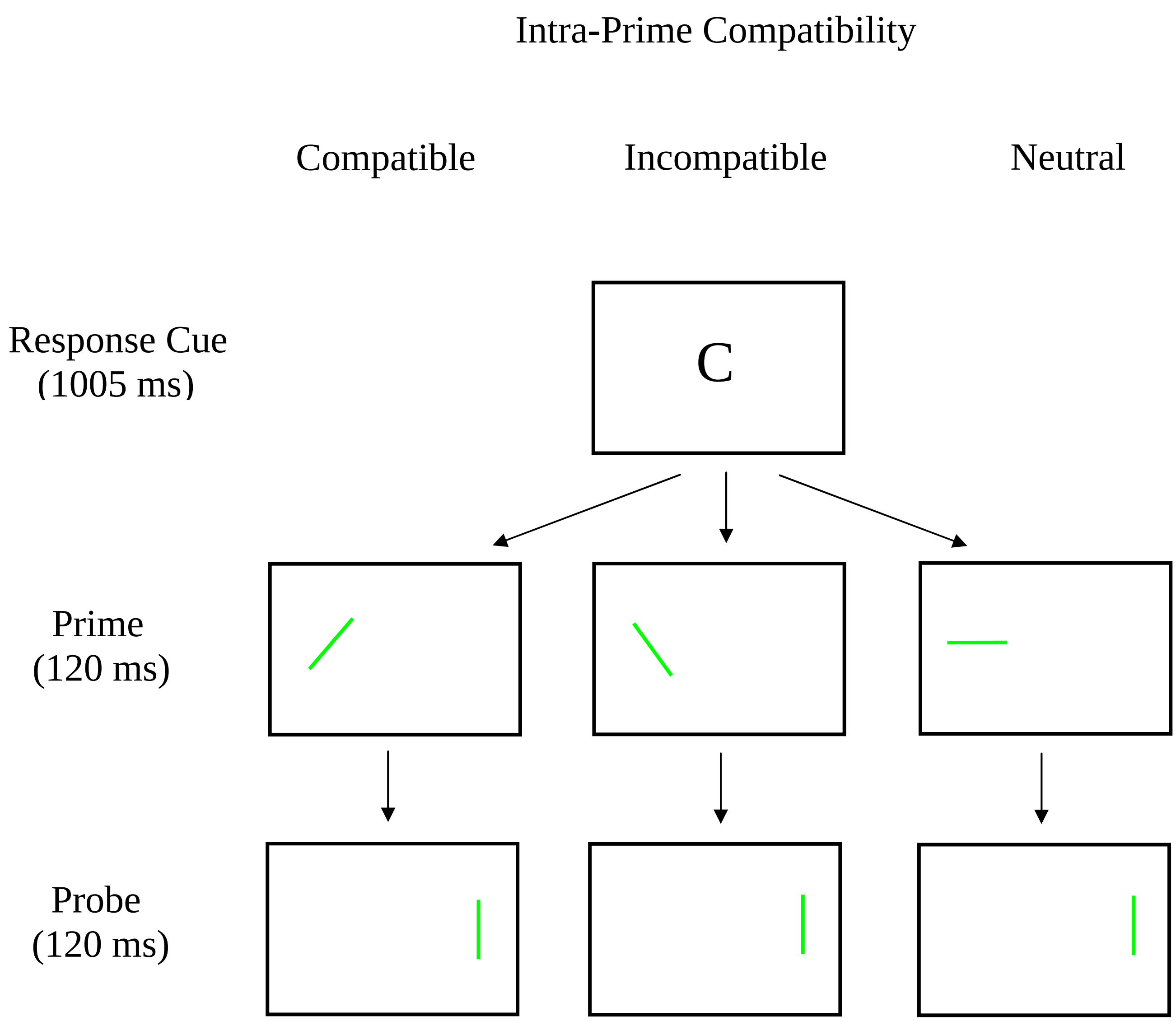
Table 6

Mean reaction times (in milliseconds) and error rates (percent incorrect), with standard errors in parenthesis, for Experiment 6.

| | Short ISI | | Long ISI | |
|---|---|---|---|---|
| Prime-Probe Similarity | Compatible | Incompatible | Compatible | Incompatible |
| | Reaction Time | | | |
| Same | 557 (21.5) | 569 (20.3) | 529 (19.9) | 540 (20.1) |
| Different | 664 (23.7) | 678 (25.5) | 581 (24.3) | 591 (21.7) |
| | Error Rate | | | |
| Same | 2.4 (0.49) | 5.1 (0.96) | 3.0 (0.57) | 5.8 (1.17) |
| Different | 6.8 (1.15) | 6.8 (1.15) | 6.4 (1.05) | 6.2 (1.34) |

Figure Caption

Figure 1. Examples of stimulus displays in Experiment 1. The task was to respond to the probe's color (red or green) or orientation (left or right) as specified by the response cue, with a *C* referring to color, and an *O* to orientation. Participants pressed one key if the response was *red* or *left*, and a different key if it was *green* or *right*. The two principal manipulations were prime-probe similarity (same or different) and intra-prime compatibility (compatible, incompatible, or neutral). The *prime-probe similarity* refers to the inter-object relationship between the relevant dimensions of the prime and probe. The *intraprime compatibility* refers to the intra-object relationship between the relevant and irrelevant dimensions within the prime. In the examples shown here, the task was to respond to color. Assume that both the prime and probe were green. The prime-probe identity would be the same, for their relevant dimensions were the same color. Trials were compatible when the two prime dimensions indicated the same response key (e.g., a green line with a right tilt), incompatible when they indicated different response keys (e.g., a green line with a left tilt), and neutral when the irrelevant prime dimension was not associated with any response keys (e.g., a green line with a horizontal orientation).


Intra-Prime Compatibility
Compatible
Incompatible
Neutral
Response Cue
(1005 ms)
C
Prime
(120 ms)
Probe
(120 ms)