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The Role of Dimension Relevance in Features' Access to Response-Selection Mechanisms

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It is widely agreed that attending to a stimulus entails that all its features are processed. However, whether all these features are granted access to response-selection mechanisms remains a debated issue. Some authors suggest that all the features of the attended object affect response selection, irrespective of their relevance to the task at hand, whereas others claim that only its currently relevant features do. Yet others suggest that irrelevant features of an attended object affect response selection only if this object is the target, that is, only if it is selected for action. The results from 3 experiments show that responses associated with an attended object's irrelevant dimension interfered with response selection even when this object was not selected for action, but to a lesser extent than the responses associated with its relevant dimension. Our findings also show that interference from the irrelevant dimension can be masked when the response codes associated with the relevant and irrelevant dimensions compete. We suggest a parsimonious account of the findings from the extant literature that obviates the need to postulate a qualitative distinction between attention and selection for action.

Keywords: attention, selection, interference, compatibility effects, stimulus-response binding

Many theories posit that attending to an object entails that all the properties of this object are mandatorily processed (e.g., Duncan, 1984; Kahneman & Henik, 1981; Shih & Sperling, 1996; Treisman & Gelade, 1980). The assumption is that once attention has been allocated to an object, the observer's ability to control which dimensions or parts of that object are fully perceived is lost: not only the relevant features but also the irrelevant features of the attended object are processed. Abundant evidence for this claim comes from studies in which processing irrelevant parts or features of an attended target is detrimental to performance on the task at hand (see Chen, 2005; Chen & Cave, 2006; Remington & Folk, 2001 for review). For instance, in the Stroop effect (e.g., Kahneman & Chajczyk, 1983; Stroop, 1935), naming the color of the ink in which an attended word is printed is slowed if the word's meaning is incompatible with the ink color.

However, that a feature is identified does not necessarily entail that this feature will affect behavior. After perceptual processing, feature representations go through additional modulations at the response level (Henson, Eckstein, Waszak, Frings, & Horner, 2014). In order to fully characterize attentional selectivity, it is crucial to understand the conditions under which stimulus-response bindings are activated (see Hommel, 1998, 2004, 2005) and more particularly, to elucidate the role of a feature's relevance to the task at hand in granting its associated responses access to response mechanisms.

Despite extensive research spanning over several decades, there is still considerable variance in the answers that have been suggested to this question. Some authors propose that all features of an attended object have full access to response execution mechanisms, regardless of their relevance. For instance, Kahneman and Henik (1981) suggested that "the attention allocated to an object potentiates the processing of all aspects of that object and the instigation of all responses associated with it, whether or not these responses are relevant" (cited in Kahneman & Chajczyk, 1983, p. 498). To substantiate this claim, they relied on the finding that features from an irrelevant dimension of a distractor object affect responses when this object is attended.

By contrast, other theorists suggest that only some features of an attended object can gain access to response processes, while other features are completely excluded. On the one hand, Cohen and Shoup (1997) suggested that "stimuli that appear to be fully processed by the perceptual system may or may not affect response selection processes, depending on whether they are associated with responses on the basis of the same dimension as the target" (p. 163). They used a variant of the flanker task (Eriksen & Eriksen, 1974), in which the target was defined on one of two possible dimensions. The flankers were always associated with a response on one dimension and were neutral on the other dimension. The authors found that only flankers' features in the target's response dimension interfered with performance.

On the other hand, Lachter, Remington, and Ruthruff (2009) suggested that "features of an object do not automatically activate responses unless that object is selected for action" (p. 995). This conclusion relied on the results of follow-up experiments that these authors conducted on a study by Remington and Folk (2001). The

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target was a unique red letter among three gray nontarget letters. On each trial, participants were instructed about which of two possible dimensions defined the response. The location of a precue that shared the target's color and thus produced contingent attentional capture (Folk, Remington, & Johnston, 1992) determined whether spatial attention was drawn toward the target or toward a nontarget (see Figure 1 for the depiction of a similar sequence of events with displays including two instead of four items). The target's irrelevant dimension was always associated with a response that was either compatible or incompatible with the response. Two of the nontargets were always neutral (i.e., they were not associated with a response on either the relevant or the irrelevant dimensions), but one of the nontargets (henceforth, the foil) was associated with a response on both the relevant and the irrelevant dimension (see Figure 2 for a description of the compatibility effects associated with the target's and foil's dimensions). Remington and Folk (2001) found that the target's irrelevant dimension interfered with response, both when the target appeared at the cued location and when it appeared at an uncued location. With regard to the foil, however, when its location was cued (i.e., when it benefitted from focused attention), only its relevant dimension but not its irrelevant dimension interfered with response. Furthermore, when the foil's location was not cued, interference from neither its relevant nor its irrelevant dimension was observed. Lachter et al. (2009) reported a similar pattern of results when participants were instructed about the relevant dimension only after they had identified the target, suggesting that these effects occurred at a postperceptual stage.

These findings suggest that when a spatially attended stimulus is selected for action, both its task-relevant and its task-irrelevant dimensions compete for response control, whereas when it is not selected for action, response activation occurs only for its task-relevant dimension. These conclusions are provocative because they postulate a qualitative difference in the processing of attended objects that are selected for action relative to attended objects that are not, rather than quantitative differences resulting from the differential amount of sustained attention these objects receive, as assumed by most models of attention.

In addition, lack of any interference from the irrelevant dimension of an attended distractor stands in contradiction with the findings from many separated-Stroop studies showing that the (irrelevant) meaning of a spatially attended distractor affects the naming latency of an adjacent target's ink color (e.g., Gatti & Egeth, 1978; Kahneman & Henik, 1981). Lachter et al. (2009) had to append additional assumptions to their model in order to accommodate this inconsistency (as did Cohen & Shoup, 1997, see p. 176).

Given the far-reaching implications of Remington and colleagues' claims (Lachter et al., 2009; Remington & Folk, 2001), it is important to critically evaluate any alternative explanation for the results on which they rely. On the one hand, their paradigm is

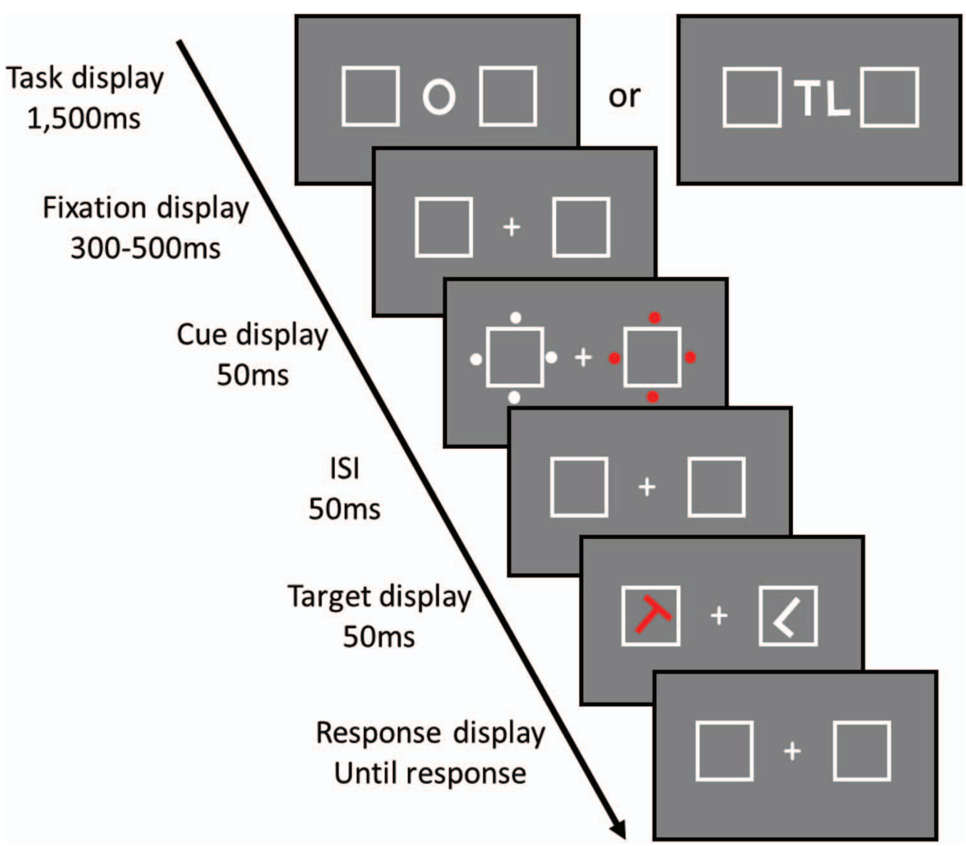

Figure 1. Sample sequence of events in Experiment 1. In this example, the target is a T and appears at the uncued location, which corresponds to the foil–location cue condition. See the online article for the color version of this figure.

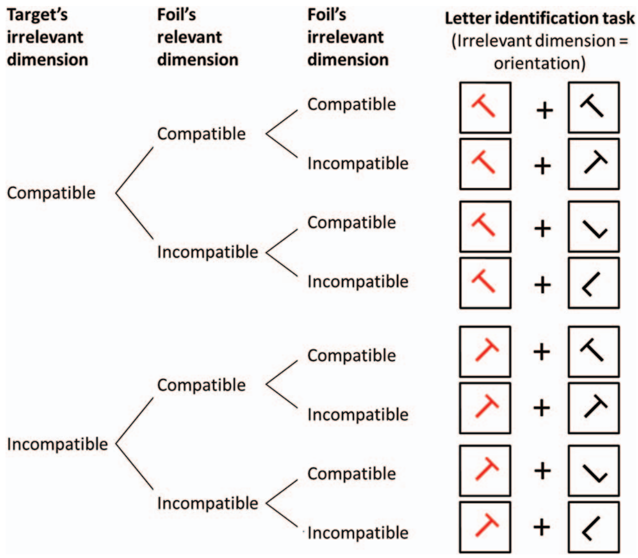

Figure 2. Compatibility conditions in Experiment 1. In this example participants had to respond to the letter identity ("T") while ignoring its orientation; "left-tilted" and "T" were associated with a left-hand response, while "right-tilted" and "L" were associated with a right-hand response. For each dimension (i.e., in each column), compatibility refers to the compatibility with the correct response. See the online article for the color version of this figure.

unique in providing the means to examine how spatial attention and task relevance interact to govern access to response execution processes. Indeed, it fulfills two critical requirements. First, the interference emanating from a *distractor* object can be measured and consequently, the interference originating from the relevant and from the irrelevant dimensions of this object can be compared. This is not the case in classical Stroop studies (including Kahneman & Henik, 1981 separated Stroop study), for instance, in which only interference from an irrelevant dimension is measured and the role of task relevance is therefore not evaluated. Second, attention to the critical object can be tightly controlled, unlike in Cohen and Shoup's (1997) study, for instance, in which attention was focused on the target and the critical flanker was therefore only partially attended.

On the other hand, however, it is noteworthy that this paradigm differs from other paradigms in one important respect. In standard separated Stroop experiments, the distractor's feature on the relevant dimension (i.e., its color) is not associated with any of the possible responses and is therefore neutral. In contrast, in Remington's studies (Lachter et al., 2009; Remington & Folk, 2001), the distractor's relevant dimension was never neutral: It was always associated with a response. Thus, interference from the relevant dimension may have masked interference from the irrelevant dimension. This could happen if, for example, under conditions of stronger conflict subjects recruit top-down control to a larger extent (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001) in order to reduce conflict, with such control overriding the effect of the irrelevant dimension.[1]

If our conjecture that interference from the relevant dimension masks interference from the irrelevant dimension, then interference from a distractor's irrelevant dimension should not be observed when this distractor's feature on the relevant dimension is also associated a response (Experiment 1), but such interference should be apparent when the feature on the relevant dimension is neutral (Experiments 2 and 3). These predictions differ from Lachter et al.'s (2009), who postulate that the irrelevant dimension of an object that is not selected for action (i.e., a distractor) should not interfere with response under any condition. They also differ from the predictions from Cohen and colleagues' Dimensional Action model (Cohen & Shoup, 1997; Magen & Cohen, 2002), according to which features from a response-irrelevant dimension should never interfere with response.

Importantly, by suggesting that the relevant and irrelevant dimensions of an attended object compete for response control both when this object is selected for action and when it is not, our alternative account obviates the need for a qualitative distinction between attention and selection for action.

Experiment 1

The design of Experiment 1 was similar to Remington and Folk's (2001) with the notable exception that each display contained only two instead of four objects (see Figure 1).[2] On each trial, three main events occurred. First, a task cue informed the participants about which dimension of the target they should respond to on the current trial: its identity (T or L) or its orientation (left or right). Then, a group of dots appeared around each of the two frame placeholders, one in the target color (the cue) and the other in gray. The cue was expected to draw attention to its location (Folk et al., 1992). Finally, a target letter, defined by its red color, and a gray distractor letter (henceforth, foil) appeared each in one frame. Each of the two letters was either T or L and was tilted to either the left or right. The cue and target letter locations were uncorrelated. Crucially, the same response was associated with one feature on each dimension (e.g., L and right tilt) and another response was associated with the other feature on each dimension (e.g., T and left tilt). Thus, response-compatibility effects could be measured (a) from the task-irrelevant dimension of the target; (b) from the task-relevant dimension of the foil; and (c) from its task-irrelevant dimension, both when the critical object was cued (and presumably inside the focus of attention) and when it was uncued (and presumably outside the focus of attention).

We expected to fully replicate Remington and Folk's (2001) findings. In particular, when the foil's location was cued (and the foil was therefore attended), we expected to find compatibility effects from the relevant dimension but not from the irrelevant dimension of the foil. When the foil's location was uncued, we expected no compatibility effect from either the relevant or the irrelevant dimension. Finally, we also expected compatibility effects from the target's irrelevant dimension: these should not be modulated by the cue location because the target should eventually

[1] It is noteworthy that in Lachter et al.'s (2009) first experiment, unlike in Remington and Folk's (2001) study, the features on only *one* of the target's dimensions were associated with a response. However, the foil's features on both its relevant and its irrelevant dimensions were associated with a response. Thus, our alternative account also holds for Lachter et al.'s (2009) study (Exp. 1).

[2] This change was introduced in order to increase the number of trials per condition, which was especially critical in Experiments 2 and 3.

benefit from attention whether or not its location was initially cued.

Method

Participants. Twelve Tel Aviv University undergraduate students (mean age 25.41, $SD = 3.02$, seven women) participated in the experiment as part of a course requirement. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus. Displays were presented in a dimly lit room on a 23" LED screen, using 1,920 × 1,280 resolution graphics mode and 120 Hz refresh rate. Responses were collected via the computer keyboard. A chin-rest was used to set viewing distance at 50 cm from the monitor.

Stimuli. Sample displays are presented in Figure 1. The fixation display consisted of a 0.2° × 0.2° plus fixation sign presented in center of the screen and flanked by two 1.7° × 1.7° placeholder boxes on the left and on the right, the centers of which were distant by 4°. All displays were similar to the fixation display except for the following changes. In the task display the plus sign was replaced with the letter "O" on orientation identification trials and with the characters "TL" on identity identification trials. In the cue display, four small dots subtending 0.48° in diameter appeared in cardinal configuration around each placeholder box. One set was red and the other was gray. In the target display a letter appeared in the center of each placeholder: One letter (the target) was red and the other (the foil) was gray. The letters were T or L, each rotated by 45° either rightward or leftward and subtending 0.8°x0.5°. All displays were presented against a black background.

Procedure. The participants were instructed to make speeded manual responses with their right hands, while maintaining high accuracy, using the numerical keypad. Each trial began with the task display, presented for 1,500 ms, in which the symbol indicated the response dimension for that trial. On orientation trials, participants were instructed to press "1" when the target was titled to the left and "3" when it was titled to the right. On identity trials, participants were instructed to press "1" when the target was a "T" and "3" when it was an "L." The task display was followed by the fixation display for a random duration between 300 ms and 500 ms. Then the cue display appeared for 50 ms and was followed by the fixation display for 50 ms. The target display was then presented for 50 ms and was followed by a response display, identical to the fixation display, which remained on the screen for 3,000 ms or until response. A blank 500-ms intertrial interval was presented before the next trial began.

Design. Subjects completed 30 practice trials followed by 10 blocks of 64 experimental trials each. Target and foil locations were randomly assigned on each trial. The location of the cue matched the location of the target (target-location cue condition) on exactly half of the trials and matched the location of the foil (foil-location cue condition) on the other half of the trials. The two types of cue-location trials were randomly mixed across the experiment. Orientation and identity trials were equiprobable and randomly mixed. Three types of response compatibility were defined with respect to the match with the response associated with the target's relevant dimension on a given trial (see Figure 2): irrelevant target–dimension compatibility, relevant foil–dimension compatibility, and irrelevant foil–dimension compatibility. Conditions for all three compatibility types were equiprobable and randomly mixed.

Results

Preliminary analyses showed a main effect of task in this and the next experiments, with faster and more accurate performance on the orientation task than on the identity task. Moreover, the effect of foil-target compatibility was significantly larger on the orientation dimension than on the identity dimension, but this interaction was not significantly modulated by any of the variables of interest in this study: in other words, it occurred to the same extent across conditions (see Tables 1, 2 and 3).[3] Therefore, here and in the next experiments, we collapsed the data across tasks, for clarity purposes.

All reaction time (RT) analyses were conducted on correct trials (95.0% of all trials). Reaction times faster than 150 ms, or exceeding the mean of their cell by more than 2.5 standard deviations (fewer than 3.0% of all correct trials) were also removed from analysis.

An analysis of variance (ANOVA) with cue location (target vs. foil), target's irrelevant–dimension compatibility (compatible vs. incompatible), foil's relevant–dimension compatibility (compatible vs. incompatible), and foil's irrelevant–dimension compatibility (compatible vs. incompatible) as within-subject factors was conducted on the mean RT and accuracy data. Mean compatibility effects are presented in Figure 3.

Reaction times. The main effect of cue location approached significance, $F(1, 11) = 4.56$, $p = .056$, $\eta_p^2 = .29$, indicating a trend toward faster RTs when the cue appeared at the target's location than at the foil's location. The main effect of the target's irrelevant-dimension compatibility was significant, $F(1, 11) = 10.78$, $p = .007$, $\eta_p^2 = .50$, with faster RTs when the target's feature on its irrelevant dimension was compatible with the response than when it was incompatible with it. This effect did not interact with the cue location, $F < 1$, $\eta_p^2 = .02$. The main effect of the foil's relevant-dimension compatibility was also significant, $F(1, 11) = 43.39$, $p < .0001$, $\eta_p^2 = .79$. This effect interacted with cue location, $F(1, 11) = 7.25$, $p = .021$, $\eta_p^2 = .40$, indicating that the compatibility effect was larger when the cue appeared at the foil's location, 83 ms, $F(1, 11) = 40.46$, $p < .0001$, $\eta_p^2 = .78$, than at the target's location, 52 ms, $F(1, 11) = 20.29$, $p < .001$, $\eta_p^2 = .64$. Finally, the effect of the foil's irrelevant–dimension compatibility was not significant nor did it interact with cue location, both $F\text{s} < 1$.

The three-way interaction between cue location, target's irrelevant-dimension compatibility and foil's irrelevant-dimension compatibility was significant, $F(1, 11) = 10.60$, $p = .008$, $\eta_p^2 = .49$. This interaction was clarified in two separate ANOVAs, one for each condition of cue location. When the cue appeared at the target's location, the interaction between the target's and the foil's irrelevant dimension compatibility was not significant, $F < 1$, $\eta_p^2 = .03$. When the cue appeared at the foil's location, this interaction was significant, $F(1, 11) = 17.79$, $p = .001$, $\eta_p^2 = .26$,

[3] These results are consistent with the notion that low-level features (e.g., orientation) are processed faster and require less attentional resources than high-level features, such as feature conjunctions and semantic content (Treisman & Gelade, 1980; Wolfe, 1994).

Table 1
Mean Reaction Times (ms) and Accuracy Rates (%) in Experiment 1, as a Function of Task (Orientation vs. Letter Identification) and Cue Location (Foil vs. Cue) for Each Condition of Compatibility (Compatible vs. Incompatible) Between the Target's Relevant Dimension and (a) the Target's Irrelevant Dimension, (b) the Foil's Relevant Dimension, and (c) the Foil's Irrelevant Dimension

	Cue at the foil's location		Cue at the target's location	
	Compatible	Incompatible	Compatible	Incompatible
Orientation identification task				
(a) Target's irrelevant dimension	584 (10)	592 (11)	570 (10)	575 (19)
	98.7 (.6)	97.0 (.8)	98.2 (.8)	93.6 (.7)
(b) Foil's relevant dimension	546 (13)	630 (9)	537 (13)	608 (14)
	98.5 (.7)	97.0 (.7)	96.4 (.7)	95.5 (.7)
(c) Foil's irrelevant dimension	591 (11)	582 (10)	575 (9)	570 (18)
	97.8 (.6)	97.7 (.7)	96.2 (.6)	95.7 (.8)
Letter identification task				
(a) Target's irrelevant dimension	612 (11)	667 (12)	598 (9)	642 (11)
	97.5 (.5)	88.1 (1.0)	97.4 (.8)	89.0 (1.4)
(b) Foil's relevant dimension	602 (9)	673 (12)	603 (12)	632 (10)
	92.7 (.9)	92.9 (.7)	92.8 (.6)	93.5 (.9)
(c) Foil's irrelevant dimension	642 (8)	634 (10)	622 (15)	613 (8)
	91.9 (.8)	93.7 (.7)	93.2 (.5)	93.0 (.6)

Note. Within-subject standard errors (Morey, 2008) are presented in parentheses.

indicating that the effect of compatibility between the target's relevant and irrelevant dimensions was larger when the foil's feature on its irrelevant dimension was compatible, 48 ms, $F(1, 11) = 16.79$, $p = .002$, $\eta_p^2 = .60$, than when it was incompatible, 16 ms, $F(1, 11) = 2.51$, $p = .14$, $\eta_p^2 = .18$.

Accuracy. There was no indication of a speed–accuracy trade-off. Participants were more accurate when the target's irrelevant-dimension was compatible than when it was incompatible with the response feature, $F(1, 11) = 35.1$, $p < .0001$, $\eta_p^2 = .76$ ($M = 98.0\%$, vs. $M = 91.9\%$). No other effect was significant, all $ps > .11$.

Discussion

The results from Experiment 1 replicated Remington and Folk's (2001) main findings. First, compatibility effects were observed both from the target's irrelevant dimension and from the foil's relevant dimension. Second, spatial attention modulated the former but not the latter effect. Third and most critically, there was no compatibility effect from the foil's irrelevant dimension.

The finding that the compatibility from an *uncued* foil's relevant dimension produced a significant effect is somewhat surprising—although a similar trend, the significance of which was not reported, was apparent in Remington and Folk's (2001)study (Figure 2). This result suggests that the foil was fully processed even when uncued, which raises the possibility that spatial attention may not have been tightly controlled in our experiment. Yet, this conjecture is unlikely because the compatibility effect was much smaller when the foil was uncued than when it was cued. This finding indicates that attention did not remain distributed across the visual

Table 2
Reaction Times (ms) and Accuracy (%) as a Function of Task (Identity vs. Orientation), Cue Location (Foil vs. Target), Foil's Dimension Relevance (Relevant vs. Irrelevant), and Foil-Target Compatibility (Compatible vs. Incompatible) in Experiment 2

	Cue at the foil's location		Cue at the target's location	
	Compatible	Incompatible	Compatible	Incompatible
Orientation identification task				
Foil's relevant dimension	445 (11)	517 (11)	423 (11)	460 (13)
	98.7 (1.0)	96.9 (1.1)	98.2 (.8)	94.9 (1.6)
Foil's irrelevant dimension	488 (13)	502 (11)	445 (11)	434 (12)
	97.7 (.9)	97.9 (.8)	98.1 (.9)	98.1 (.8)
Letter identification task				
Foil's relevant dimension	554 (10)	591 (10)	525 (11)	549 (6)
	93.7 (1.5)	94.3 (1.2)	93.4 (1.5)	94.5 (.8)
Foil's irrelevant dimension	590 (15)	622 (19)	583 (15)	555 (12)
	93.8 (1.1)	92.2 (1.2)	93.8 (.9)	93.4 (1.1)

Note. Within-subject standard errors (Morey, 2008) are presented in parentheses.

Table 3
Reaction Times (ms) and Accuracy (%) as a Function of Task (Identity vs. Orientation), Cue Location (Foil vs. Neutral Distractor vs. Target), Foil's Dimension Relevance (Relevant vs. Irrelevant), and Foil-Target Compatibility (Compatible vs. Incompatible) in Experiment 3

	Cue at the foil's location		Cue at the neutral distractor's location		Cue at the target's location	
	Compatible	Incompatible	Compatible	Incompatible	Compatible	Incompatible
Orientation identification task						
Foil's relevant dimension	538 (12)	621 (12)	562 (7)	604 (16)	518 (11)	540 (12)
	97.7 (.7)	96.7 (.8)	97.7 (.9)	98.4 (.6)	98.5 (1.0)	98.5 (.5)
Foil's irrelevant dimension	558 (14)	589 (13)	573 (9)	574 (11)	523 (13)	507 (17)
	97.7 (.7)	98.0 (.7)	97.7 (.7)	98.4 (.7)	97.8 (.8)	98.5 (.9)
Letter identification task						
Foil's relevant dimension	617 (14)	656 (15)	630 (15)	614 (10)	556 (11)	571 (10)
	96.9 (1.5)	96.0 (1.1)	95.0 (1.4)	93.5 (1.6)	96.6 (1.0)	97.8 (.6)
Foil's irrelevant dimension	654 (16)	672 (17)	644 (13)	610 (8)	565 (13)	585 (10)
	95.4 (.7)	96.0 (1.0)	96.6 (.6)	96.3 (.9)	98.5 (.7)	98.5 (.8)

Note. Within-subject standard errors (Morey, 2008) are presented in parentheses.

field and that our cues successfully drew spatial attention to their location—as does the clear trend toward a location benefit on validly cued trials.

Experiment 2

Having replicated Remington and Folk's (2001) main findings with our apparatus and displays, we set out to determine whether interference from the foil's irrelevant dimension can be observed when the conflict between the foil's relevant and irrelevant dimensions is reduced. Experiment 2 was similar to Experiment 1 except that neutral values (i.e., values that were not associated with any response) were added for each dimension of the target and foil: "N" on identity and "vertical" on orientation. Our main interest was in "single-dimension trials," in which one dimension (of the foil or of the target) had a feature associated with a response and the feature on its other dimension was neutral (see Figure 4 for a concrete illustration of single-dimension displays). In other words, we focused on trials in which the conflict between the two dimensions of the critical object was reduced. On such trials, we expected to observe compatibility effects from both the relevant and the irrelevant dimensions of a spatially cued foil. Two-dimension foil and two-dimension target trials were included in the experiment mainly in order to discourage participants from ignoring the task cue and adopting the strategy of relying on the target's response feature in order to infer what task was relevant on the current trial. In all the analyses reported here the two-dimension

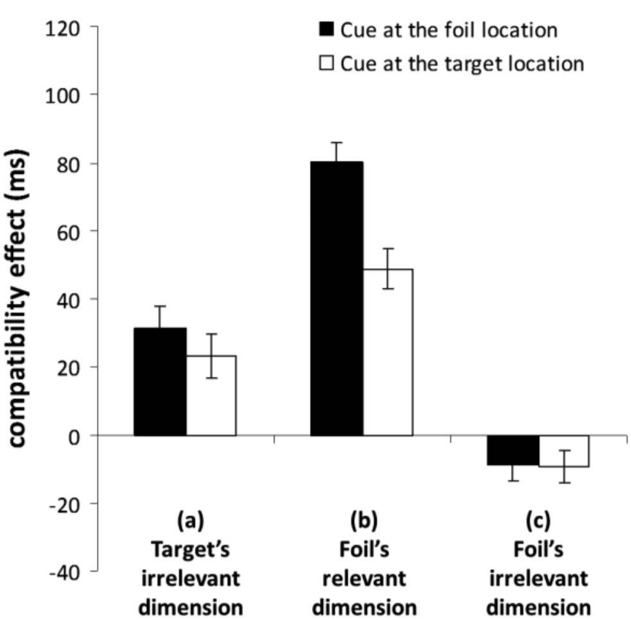

Figure 3. Mean compatibility effect (mean RT on incompatible trial minus mean RT on compatible trials) between the target's relevant dimension and (a) the target's irrelevant dimension; (b) the foil's relevant dimension; and (c) the foil's irrelevant dimension, as a function of cue location (foil vs. target) in Experiment 1. Error bars denote within-subject standard errors (Morey, 2008).

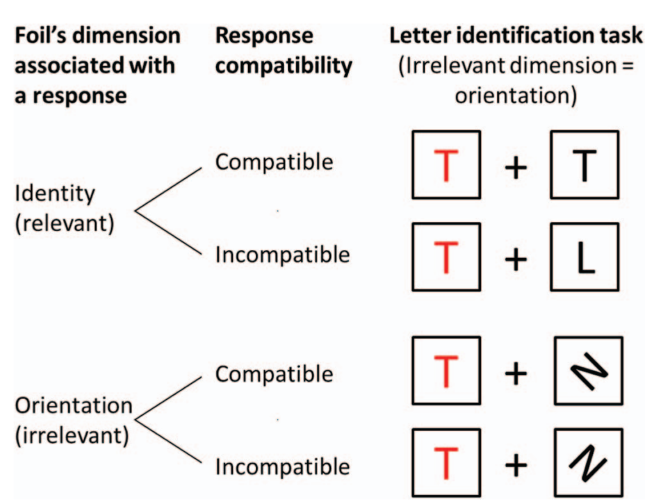

Figure 4. Compatibility conditions in Experiment 2 (single-dimension target and single-dimension foil conditions only). In this example participants had to respond to the identity of the red (target) letter, "T," while ignoring its orientation. See the online article for the color version of this figure.

target trials were excluded. The small number of two-dimension foil trials nevertheless allowed us to examine whether our design successfully replicated previously reported results (a compatibility effect in the cued foil's relevant dimension but not in the cued foil's irrelevant dimension), as well as to test our conjecture that two-dimension foil trials entailed a conflict between the foil's relevant and irrelevant dimensions.

Method

Participants. Sixteen Tel Aviv University undergraduate students (mean age 24.83, SD = 2.48, eight women) participated in the experiment as part of a course requirement. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design. The apparatus, stimuli, procedure and design were similar to those of Experiment 1 except for the following changes in the target display. The target and foil letters were "T," "L" (response-associated identities), or "N" (neutral identity). The target and foil letters were either tilted to the left or right (response-associated orientations), or upright (neutral orientation). On single-dimension foil trials (80% of the trials), the foil's feature on one dimension (either the relevant or the irrelevant dimension) was associated with a response and its feature on the other dimension was neutral (see Figure 4). Trials in which the relevant versus the irrelevant dimension of the foil was associated with a response were equiprobable and randomly mixed. On two-dimension foil trials (20% of the trials) the foil's features on both the relevant and the irrelevant dimensions were associated with a response. On single-dimension target trials (80% of the trials), the target's feature on the irrelevant dimension was neutral (see Figure 4), whereas on two-dimension target trials (20% of the trials) it was associated with a response. Thus, only one dimension of the foil and one dimension of the target were associated with a response on 64% of the trials (80% × 80%), one dimension of the foil and two dimensions of the target were associated with a response on 16% of the trials (80% × 20%) and vice versa on 16% of the trials (80% × 20%) and two dimensions of the foil and target were associated with a response (as in Experiment 1) on 4% of the trials (20% × 20%). Whenever a feature was associated with a response, it was equally likely to be compatible or incompatible with the response associated with the target's relevant feature. Foil and target single- and two-dimension trials as well as compatible and incompatible trials were randomly mixed.

As in Experiment 1, participants completed 30 practice trials followed by 10 blocks of 64 experimental trials each.

Results

The results from one subject were excluded from the analysis because his overall accuracy was lower than the group's mean by more than three standard deviations (M = 79.0% vs. M = 95.6%, SD = 3.8%). All RT analyses were conducted on correct responses and excluding RT outliers (fewer than 2.0% of all correct trials).

Single-dimension foil compatibility effects. In order to test our main hypothesis, we included only trials in which for both the target and the foil, only the features on one dimension were associated with a response (see Figure 4). An ANOVA with cue location (target vs. foil), foil's dimension relevance (relevant vs. irrelevant) and foil–target compatibility (compatible vs. incompatible) as within-subject factors was conducted on the mean RT and accuracy data. Mean compatibility effects are presented in Figure 5.

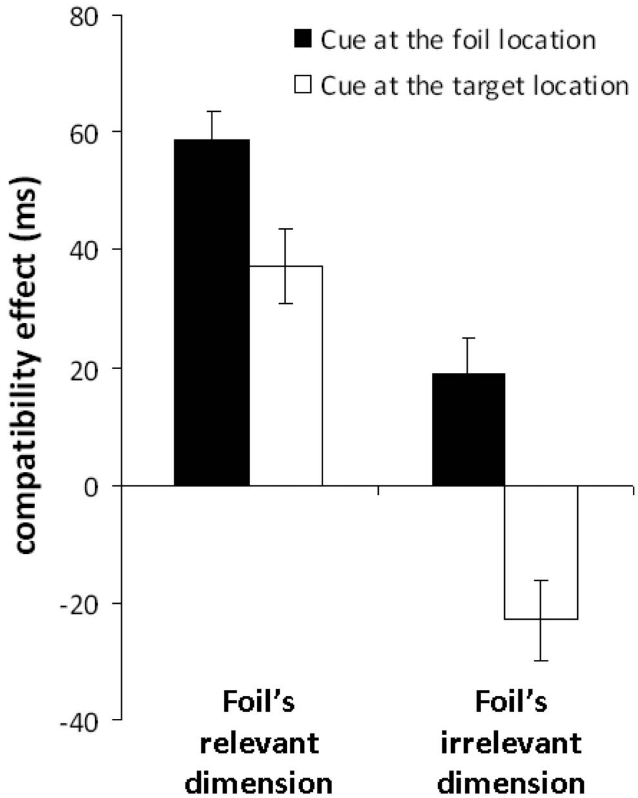

Figure 5. Mean compatibility effect (mean RT on incompatible trials minus mean RT on compatible trials) as a function of foil's dimension relevance (relevant vs. irrelevant) and cue location (foil vs. target) in Experiment 2. Error bars denote within-subject standard errors (Morey, 2008).

Reaction times. All main effects were significant, $F(1, 14) = 102.21$, $p < .0001$, $\eta_p^2 = .88$, $F(1, 14) = 15.30$, $p < .002$, $\eta_p^2 = .52$, and $F(1, 14) = 47.62$, $p < .0001$, $\eta_p^2 = .77$, for cue location, foil's dimension relevance, and foil–target compatibility, respectively. Reaction times were faster when the cue appeared at the target's location than at the foil's location, when the foil's dimension was relevant than when it was irrelevant and when the foil's feature was compatible with the target than when it was incompatible with it.

Foil-target compatibility interacted with cue location, $F(1, 14) = 41.50$, $p < .0001$, $\eta_p^2 = .75$, as well as with foil's dimension relevance, $F(1, 14) = 40.06$, $p < .0001$, $\eta_p^2 = .74$. Follow-up analyses indicated that the compatibility effect was larger when the cue appeared at the foil's location, $F(1, 14) = 66.15$, $p < .0001$, $\eta_p^2 = .83$, than at the target's location, $F(1, 14) = .42$, $p = .054$, $\eta_p^2 = .24$, and when the foil's dimension was relevant, $F(1, 14) = 83.66$, $p < .0001$, $\eta_p^2 = .86$, than when it was irrelevant, $F < 1$, $\eta_p^2 = .01$.

It is noteworthy that the nonsignificant three-way interaction, $F(1, 14) = 1.74$, $p = .21$, $\eta_p^2 = .11$, masked a markedly different pattern in the same relative to the different cue-location conditions.

For each cue-location condition, the compatibility effect was significantly larger for the relevant than for the irrelevant dimension (hence, the absence of a three-way interaction). However, when the cue appeared at the foil's location, the compatibility effect was positive (i.e., RTs were *faster* on compatible than on incompatible trials) on both the relevant dimension (M = 59 ms, $F(1, 14) = 92.60$, $p < .0001$, $\eta_p^2 = .87$), and the irrelevant dimension, (M = 19 ms, $F(1, 14) = 6.39$, $p = .024$, $\eta_p^2 = .31$), whereas when the cue appeared at the target's location, the compatibility effect was again positive on the relevant dimension (M = 37 ms, $F(1, 14) = 27.07$, $p < .0001$, $\eta_p^2 = .66$), but it was negative (*slower* RTs on compatible than on incompatible trials) on the irrelevant dimension (M = −23 ms, $F(1, 14) = 11.26$, $p = .005$, $\eta_p^2 = .45$).

Accuracy. A similar ANOVA on accuracy yielded no significant effect, all Fs < 1.

Two-dimension foil compatibility effects. To examine whether the findings of Experiment 1 were replicated in the present experiment, we conducted an analysis on two-dimension *foil* trials. An ANOVA with cue location (target vs. foil), foil's relevant–dimension compatibility (compatible vs. incompatible) and foil's irrelevant–dimension compatibility (compatible vs. incompatible) as within-subject factors was conducted on mean RTs and accuracy data.

Reaction times. The main effect of cue location was significant, $F(1, 14) = 21.93$, $p < .001$, $\eta_p^2 = .61$, with faster RTs when the cue appeared at the target's than at the foil's location. The main effect of foil's relevant–dimension compatibility was also significant, $F(1, 14) = 53.0$, $p < .0001$, $\eta_p^2 = .79$. This effect was modulated by cue location, $F(1, 14) = 4.94$, $p = .04$, $\eta_p^2 = .26$, with a larger compatibility effect when the cue appeared at the foil's location, 88 ms, $F(1, 14) = 57.7$, $p < .0001$, $\eta_p^2 = .84$, than at the target's location, 58 ms, $F(1, 14) = 19.3$, $p < .001$, $\eta_p^2 = .57$. The effect of the foil's irrelevant–dimension compatibility was not significant, F < 1, $\eta_p^2 = .001$, and did not interact with cue location, $F < 1$, $\eta_p^2 = .06$. No other effect was significant, all Fs < 1.

Accuracy. Accuracy effects mirrored the RTs effects. The main effect of cue location approached significance, $F(1, 14) = 3.78$, $p = .07$, $\eta_p^2 = .21$, with a trend toward higher accuracy when the cue was at the target's versus at the foil's location. The main effect of foil's relevant-dimension compatibility was marginally significant, $F(1, 14) = 4.54$, $p = .051$, $\eta_p^2 = .24$, and interacted with cue location, $F(1, 14) = 5.68$, $p = .03$, $\eta_p^2 = .29$. Follow-up analyses indicated that accuracy was higher when the foil's relevant-dimension was compatible with the target than when it was incompatible with it, only when the cue was at the foil's location, 1.4%, $F(1, 14) = 9.60$, $p = .008$, $\eta_p^2 = .40$, but not when it was at the target's location, 0.8%, $F < 1$, $\eta_p^2 = .03$.

Comparison between single- and two-dimension foil trials. We examined whether associating the foil's features on its irrelevant dimension with responses, on top of the features on its relevant dimension, incurred a performance cost. Such a finding would provide indirect evidence that the foil's irrelevant dimension was not totally ignored on two-dimension trials but produced a conflict with the foil's relevant dimension. We compared mean RTs and accuracy when the foil's irrelevant dimension was neutral (single-dimension foil trials) and when it was associated with a response (two-dimension foil trials).

Reaction times. Reaction times were significantly slower when the foil's irrelevant dimension was associated with a response than when it was neutral, M = 505 ms versus M = 523 ms, $F(1, 14) = 9.76$, $p = .007$, $\eta_p^2 = .41$.

Accuracy. The accuracy effect was not significant, $F(1, 14) = 3.01$, $p = .10$, $\eta_p^2 = .18$.

Discussion

The results of Experiment 2 supported our hypothesis. When the foil's location was cued and its feature on only one dimension was associated with a response (such that there was presumably no conflict between its relevant and irrelevant dimensions), a significant compatibility effect from the foil's irrelevant dimension emerged. However, this effect was smaller than the compatibility effect from this foil's relevant dimension. In contrast, when both of the foil's dimensions were associated with a response (two-dimension trials), the compatibility effect from the foil's irrelevant dimension was no longer apparent—but the association with a response of the foil's features on the irrelevant dimension (on top of the features on its relevant dimension) nevertheless slowed overall RT. We take the latter finding to reflect a conflict between the two dimensions and therefore to indicate that the foil's irrelevant dimension was not totally ignored even on two-dimension trials.

Thus, whereas our findings suggest that task demands modulate the impact of an attended object on response mechanisms, they invalidate the claim that irrelevant features of an attended distractor can be entirely shunned from response selection mechanisms (e.g., Cohen & Shoup, 1997; Lachter et al., 2009; Magen & Cohen, 2002).

One surprising finding occurred in the uncued-foil condition. When the cue had appeared at the target's location (and therefore the foil presumably did not benefit from focused attention) the foil's irrelevant dimension was associated with a *reverse* compatibility effect (i.e., faster RTs on incompatible vs. compatible trials). Reverse compatibility effects have been reported under conditions that markedly differed from those prevailing in our study—mainly with masked stimuli (e.g., Eimer & Schlaghecken, 1998, 2002) or for sequential effects (e.g., Huang, Holcombe, & Pashler, 2004).

It is noteworthy that the relevant dimension of an uncued foil again produced significant compatibility effects. Although other findings strongly suggest that the cue successfully captured attention to its location (significant cue location effect, larger compatibility effects for cued than for uncued foils), this result suggests that some attention may nevertheless have accrued to the uncued location. We address this issue in Experiment 3.

To account for the overall pattern of compatibility effects observed in Experiments 1 and 2, we suggest that spatial attention and dimension's relevance to the task additively determine a feature's impact on response selection mechanisms. Specifically, we suggest that spatially focused attention enhances the activation of response codes from all the attended object's dimensions, regardless of their relevance to task demands, with activation positively correlated to the duration of sustained attention. Thus, attentional benefits are greater for targets, on which attention is maintained, than for distractors, from which attention is quickly disengaged. In addition, the different features of objects in the visual field compete for access to response selection mechanisms, and the codes of features from currently relevant dimensions enjoy

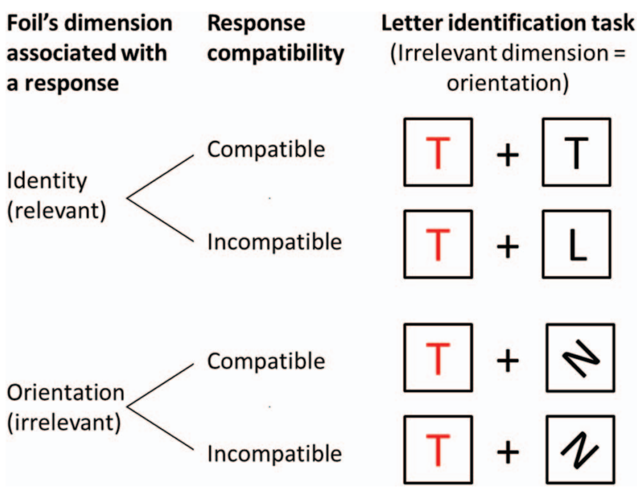

Figure 6. Illustration of the results that are expected if spatial attention and dimension relevance additively determine a feature's impact on response mechanisms, and hence, the magnitude of the compatibility effect associated with this feature. The magnitudes of the compatibility effects found in Experiments 1 and 2 match the total activation predicted and suggest that in our experiments, task relevance benefitted from a larger weight than spatial attention. See the online article for the color version of this figure.

higher activation than features from irrelevant dimensions. This tentative scheme can explain the ranking of the magnitudes of the compatibility effects found in the different conditions of Experiments 1 and 2 (see Figure 6). In order to account for the finding that the lowest-ranking condition (unattended foil's irrelevant dimension) displayed a negative compatibility effect, we further speculate that dimension relevance may determine whether a response code will be activated (if it is associated with a feature on the relevant dimension) or inhibited (if it is associated with a feature on the irrelevant dimension) during the response-selection stage.

Experiment 3

The main objective of Experiment 3 was to further establish the main finding of Experiment 2, namely, that irrelevant features of an attended distractor affect response selection mechanisms. The second objective was to determine whether the results of a new experiment, with a different experimental design that strengthened the spatial control of attention by the cue, would also conform to our post hoc account of the mechanisms underlying the gradient of compatibility effect strengths in Experiments 1 and 2. Finally, we inquired whether the unexpected reverse compatibility effect observed in Experiment 2 could be replicated.

Experiment 3 included three main changes relative to Experiment 2. Each display included three stimuli instead of just two. These stimuli were displayed further apart from each other, such that less attention, if at all, should accrue to uncued locations. Finally, in order to increase the generality of our results, the design included several pairs of possible target letters (varied between participants) instead of just T/L.

Method

Participants. Eighteen Tel Aviv University undergraduate students (mean age 22.76, $SD = 1.2$, 14 women) participated in the experiment as part of a course requirement. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design. The apparatus, stimuli, procedure, and design were similar to those of Experiment 2 except for the following changes. The target letters for each subject were one of six possible pairs: T and L, T and H, T and F, L and H, L and F, or F and H. Each display included three items that appeared in triangle configuration around fixation (see Figure 7). On every trial, the target display included three letters, the target, a foil, and a neutral distractor that was not associated with any response (e.g., a vertical E if the possible targets were T and L). The distance of each letter's center from fixation was 3° and the center-to-center distance between two letters was approximately 5.2°.

As in Experiments 1 and 2, participants completed 30 practice trials followed by 10 blocks of 64 experimental trials each.

Results

The results from one subject were excluded because her overall accuracy was lower than the group's mean by more than three standard deviations ($M = 89.9\%$ vs. an average of 96.1%, $SD = 1.9\%$). All analyses were conducted on correct responses, and excluding RT outliers (fewer than 1.2% of all correct trials).

Preliminary analyses revealed that the target-pair between-subjects variable affected the overall difficulty of the identity task: the identity task was significantly more difficult than the orientation task among the "FH," the "LF," and the "TH" groups ($ps < .05$), but not among the "TL", "FT," and "LH" groups ($ps > .10$). However, as this variable did not interact with any other factor, we collapsed the data across conditions of target pair.

Single-dimension foil compatibility effects. For this analysis, we included only trials in which both the target and the foil were associated with a single response (see Figure 7 for examples

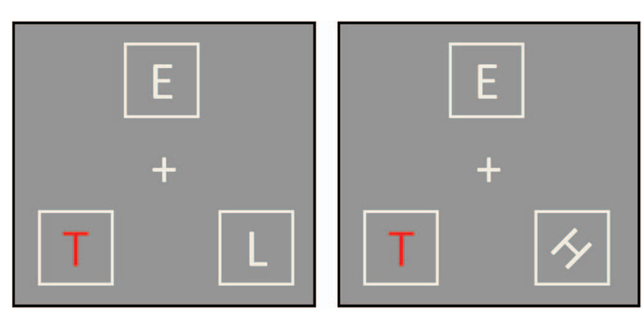

Figure 7. Sample target displays in Experiment 3. The display included a target letter, a foil, and a neutral letter. In both panels, the examples correspond to a single-dimension foil and single-dimension target trial, the task was identity, the possible target letters were T and L, and the neutral letters were E and H. In the left panel, the foil's response-associated dimension (identity) was task relevant, and in the right panel the foil's dimension (orientation) was task irrelevant. See the online article for the color version of this figure.

of single-dimension displays). An ANOVA with cue location (target vs. neutral distractor vs. foil), foil's dimension relevance (relevant vs. irrelevant) and foil-target compatibility (compatible vs. incompatible) as within-subject factors was conducted on the mean RT and accuracy data. Mean compatibility effects are presented in Figure 8.

Reaction times. The main effect of cue location was significant, $F(2, 32) = 85.54$, $p < .0001$, $\eta_p^2 = .84$. Tukey's HSD tests confirmed that response times were faster when the cue appeared at the target location than when it appeared at either of the two nontarget locations, both $ps < .001$. There was no significant difference when the cue appeared at the neutral distractor's or at the foil's location, $p > .10$. The main effect of foil–target compatibility was significant, $F(1, 16) = 15.36$, $p = .001$, $\eta_p^2 = .49$, and interacted with cue location, $F(2, 32) = 13.22$, $p < .0001$, $\eta_p^2 = .45$. Follow-up analyses revealed that the compatibility effect was larger when the cue appeared at the foil's location, $F(1, 16) = 61.38$, $p < .0001$, $\eta_p^2 = .78$, than when it appeared at the target's location, $F(1, 16) = 2.97$, $p = .10$, $\eta_p^2 = .15$, or the neutral location, $F < 1$, $\eta_p^2 = .0001$. The interaction between foil's dimension relevance and foil–target compatibility was also significant, $F(1, 16) = 40.06$, $p < .0001$, $\eta_p^2 = .74$, indicating that the compatibility effect was larger when the foil's dimension was relevant, $F(1, 16) = 28.99$, $p < .0001$, $\eta_p^2 = .64$, than when it was irrelevant, $F < 1$, $\eta_p^2 = .01$. All other effects were nonsignificant, all $Fs < 1$.

Because our main interest was in the compatibility effects from the foil's feature for each combination of task relevance and cue location, we conducted the corresponding planned comparisons.

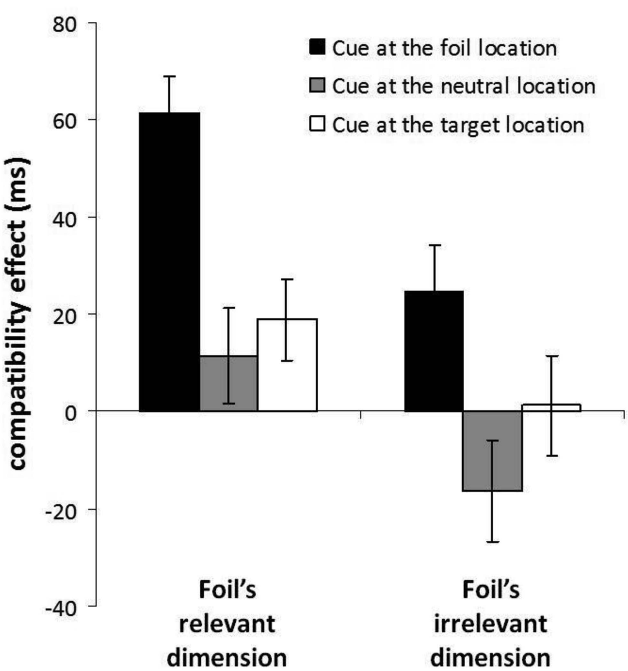

Figure 8. Mean compatibility effect (mean RT on incompatible trials minus mean RT on compatible trials) as a function of foil's dimension relevance (relevant vs. irrelevant) and cue location (foil vs. neutral distractor vs. target) in Experiment 3. Error bars denote within-subject standard errors (Morey, 2008).

The compatibility effect from the foil's relevant dimension was significant when the cue appeared at the foil's location, 62 ms, $F(1, 16) = 65.06$, $p < .0001$, $\eta_p^2 = .80$, and when it appeared at the target location, 19 ms, $F(1, 16) = 5.09$, $p = .03$, $\eta_p^2 = .23$, but not when it appeared at the neutral distractor's location, 11 ms, $F(1, 16) = 1.39$, $p = .25$, $\eta_p^2 = .07$. Most importantly for our purposes, the compatibility effect from the foil's irrelevant dimension was significant when the cue appeared at the foil's location, 25 ms, $F(1, 16) = 6.63$, $p = .02$, $\eta_p^2 = .29$. When the cue appeared at the target's location, this effect was not significant, 1 ms, $F < 1$, $\eta_p^2 = .0001$ and when the cue appeared at the neutral distractor's location, there was a nonsignificant trend toward a reverse compatibility effect, −16 ms, $F(1, 16) = 2.44$, $p = .13$, $\eta_p^2 = .12$.

Accuracy. The main effect of cue location was significant, $F(2, 32) = 4.57$, $p = .02$, $\eta_p^2 = .22$, with higher accuracy when the cue appeared at the location of the target as compared to the location of the foil or the neutral distractor. Tukey's HSD tests revealed that the difference between the target's and neutral distractor's location trials was significant ($p = .02$), while the difference between the target's and foil location trials only approached significance ($p = .06$). No other effect was significant, all $ps > .10$.

Two-dimension foil compatibility effects. To examine whether the pattern of results on two-dimension foil trials would again replicate the findings of Experiments 1 and 2, we conducted an ANOVA with cue location (target vs. neutral distractor vs. foil), foil's relevant–dimension compatibility (compatible vs. incompatible) and foil's irrelevant–dimension compatibility (compatible vs. incompatible) as within-subject factors on the mean RT and accuracy data. This analysis included only two-dimension foil trials.

Reaction time. The main effect of cue location was significant, $F(1, 16) = 16.73$, $p < .0001$, $\eta_p^2 = .51$, with faster RTs when the cue was at the target's location than at either the foil's or the neutral distractor's location. Tukey's HSD test confirmed that both these differences were significant, both $ps < .001$. The main effect of foil's relevant-dimension compatibility was significant, $F(1, 16) = 40.79$, $p < .0001$, $\eta_p^2 = .71$, and its interaction with cue location approached significance, $F(1, 16) = 3.18$, $p = .055$, $\eta_p^2 = .16$. Follow-up analyses indicated that the compatibility effect from the foil's relevant-dimension was larger when the cue appeared at the foil's location, 73 ms, $F(1, 16) = 32.18$, $p < .0001$, $\eta_p^2 = .67$, than at the neutral distractor's location, 29 ms, $F(1, 16) = 3.56$, $p = .08$, $\eta_p^2 = .18$, or the target's location, 36 ms, $F(1, 16) = 11.74$, $p = .003$, $\eta_p^2 = .42$. The main effect of foil's irrelevant-dimension compatibility was not significant, $F < 1$, $\eta_p^2 = .005$, and did not interact with cue location, $F(1, 16) = 1.67$, $p = .20$, $\eta_p^2 = .09$. No other effect was significant, all $ps > .29$.

Accuracy. The main effect of foil's relevant-dimension compatibility was significant, $F(1, 16) = 4.86$, $p = .04$, $\eta_p^2 = .23$, with higher accuracy when the foil's relevant dimension was compatible than when it was incompatible. No other effect was significant, all $ps > .13$.

Comparison between single- and two-dimension foil trials. We examined whether associating the foil's features on its irrelevant dimension with responses, on top of the features on its relevant dimension, incurred a performance cost.

Reaction times. Reaction times were slower when the foil's irrelevant dimension was associated with a response than when it was neutral, $M = 599$ ms versus $M = 586$ ms, respectively, $F(1, 16) = 4.68$, $p = .045$, $\eta_p^2 = .23$.

Accuracy. The difference between the conditions was not significant, -0.2%, $F < 1$, $\eta_p^2 = .01$.

Control of spatial attention by the cue: between-experiments comparison. We examined whether the changes introduced in Experiment 3 (i.e., adding a third location and increasing letter eccentricity) were successful in strengthening the control of spatial attention by the cue relative to Experiment 2. To do so, we excluded trials in which the cue appeared at the neutral distractor's location, and conducted an ANOVA with cue location (target vs. foil) as a within-subject factor and Experiment (2 vs. 3) as a between-subjects factor.

Reaction times. The interaction between the two factors was significant, $F(1, 30) = 14.13$, $p < .001$, $\eta_p^2 = .32$, indicating that the spatial capture effect was larger in Experiment 3 than in Experiment 2, 68 ms versus 41 ms, respectively.

Accuracy. The accuracy data mirrored the RT data. The interaction between cue location and experiment was significant, $F(1, 30) = 5.43$, $p = .026$, $\eta_p^2 = .15$, with a larger spatial capture effect in Experiment 3 than in Experiment 2, 1.6% versus -0.1%.

Discussion

Experiment 3 replicated the main findings from Experiment 2. When only one of a cued (and therefore spatially attended) distractor's features was associated with a response, both its relevant and its irrelevant dimensions produced a compatibility effect, and this effect was larger for the relevant than for the irrelevant dimension. In contrast, when both dimensions were associated with a response, compatibility effects were observed only from the foil's relevant dimension and not from its irrelevant dimension. The association of both of the foil's dimensions with a response relative to just its relevant dimension delayed overall RTs, a finding that is consistent with the idea that conflict at the response level was larger in the two- than in the single-dimension condition. Thus, the compatibility effect from an attended foil's irrelevant feature that we report in the present study is robust and generalizes across different set sizes, interstimulus distances and target letters sets.

Increasing the number of display items to three and setting them further apart from each other resulted in a larger spatial cueing effect relative to Experiment 2, confirming that attention was more tightly constrained to the cued location. Nevertheless, we again observed compatibility effects from the foil's relevant dimension when the foil's location was uncued. However, this effect was weaker than in the previous experiments. In addition, by contrast with Experiments 1 and 2, it was significant only on trials in which orientation was the relevant dimension (see Table 3), raising the possibility that unlike detection of the foil's identity, detection of its orientation may not have required focal attention.

We did not replicate the reverse compatibility effect found in Experiment 2 for the foil's irrelevant dimension. Although such failure to replicate this unexpected finding suggests that it may have been spurious, the nonsignificant trend toward a reverse compatibility effect we observed when the cue appeared at the neutral distractor's location (but not when it appeared at the target's location) raises the possibility that this effect might emerge under very specific conditions, yet to be characterized. As the reverse compatibility effect was not the focus of our study, it is not discussed further.

Finally, the findings of Experiment 3 support the hypothesis presented in Figure 6, according to which spatial attention and dimension relevance additively determine a feature's impact on response mechanisms. As predicted, compatibility effects were largest for the relevant feature of an attended distractor, and smallest for the irrelevant feature of an unattended distractor, with compatibility effects of intermediate magnitude for the relevant feature of an unattended distractor and for the irrelevant feature of an attended distractor.

General Discussion

Summary of the Main Findings

The objective of the present study was to examine this extent to which attending to an object grants this object's features access to response mechanisms. More specifically, we investigated how such access is modulated (a) by the relevance of the attended object's features to the task at hand, and (b) by whether or not this object is selected for action (i.e., whether or not it is the target). Our main findings are that responses associated with an attended object's irrelevant dimension are activated even when this object is not selected for action, but to a lesser extent than the responses associated with its relevant dimension, and that interference from the attended object's task-irrelevant dimension is masked by interference from its task-relevant dimension and clearly emerges when such competition between the two dimensions is reduced.

Relation to Existing Accounts

These findings cannot be accommodated by current accounts of response interference. On the one hand, they challenge the claim that responses associated with the relevant and irrelevant features of an object are equally potentiated when this object is attended (e.g., Kahneman & Henik, 1981). On the other hand, they contradict the idea that some features of an attended object can be entirely shunned from response selection mechanisms (e.g., Cohen & Shoup, 1997; Lachter et al., 2009; Magen & Cohen, 2002). Instead, our findings suggest that all the object's features compete to gain access to response selection mechanisms. Spatial attention enhances the strength of all the extracted response codes but features on the currently relevant dimension are granted more weight in the competition.

The idea that spatial attention and dimension relevance additively determine a feature's impact on response mechanisms can accommodate previous conflicting findings. It is consistent with Cohen and Shoup's (1997) finding that features from a currently relevant dimension produce more interference than features from an irrelevant dimension. However, it explains the absence of any interference from the irrelevant dimension in that study as a floor effect: Although Cohen and Shoup (1997) manipulated the distance between the attended location and the critical flankers' locations, flankers never benefited from focused attention.

This hypothesis also explains Remington and colleagues' findings (Lachter et al., 2009; Remington & Folk, 2001) by suggesting that when features from several dimensions compete to determine which response will be selected, such competition incurs a performance cost (as observed here in Experiments 2 and 3), and the interference from the relevant dimension can override the interference from the irrelevant dimension (as observed here in the two-dimension conditions in Experiments 1–3 which replicated the findings by Remington & Folk, 2001). However, when such competition is relaxed, interference from the irrelevant dimension can be observed (as observed in the single-dimension foil condition of Experiments 2 and 3 as well as in separated-Stroop experiments).

Finally, it also is also consistent with separated-Stroop findings (Kahneman & Chajczyk, 1983) showing significant interference from the irrelevant dimension of an attended nontarget, but underscores that failure to compare this effect with interference by the relevant dimension in these studies obscured the role of task relevance in the control of response selection.

Alternative Accounts for the Effect of Task Relevance

One could claim that our study overestimated the role of task relevance because on single-dimension trials, while the response compatibility effect from the foil's irrelevant dimension was always confounded with the effect perceptual similarity between the foil and the target on that dimension, this was never the case for the response compatibility from the foil's irrelevant dimension. Previous studies have shown that compatible flankers that are perceptually identical to the target produce a larger advantage relative to incompatible flankers than compatible flankers that are perceptually dissimilar from the target (e.g., Eriksen & Eriksen, 1974). Therefore, such advantage rather than dimension relevance may explain that the compatibility effect observed for the relevant dimension was three times as large as that observed for the irrelevant dimension (~60 ms vs. ~20 ms, respectively, in both Experiments 2 and 3; see Figures 5 and 8). Although the data from the present study cannot adjudicate this issue, differences related to perceptual similarity are unlikely to account for the entirety of the task relevance effect reported in our study because purely perceptual portion of the response compatibility effect is typically small (usually around 30% of the total effect).[4]

In addition, one may argue that the compatibility effects from the foil's irrelevant dimension in Experiments 2 and 3 may result from the participants' adopting a nonselective response strategy. Specifically, because the target's irrelevant dimension was neutral (e.g., a vertical L in an identity task) on 80% of the trials, participants could ignore the cue and successfully infer the task from the target itself: on single-dimension trials, the relevant dimension of the target was the dimension on which its feature was associated with a response. If participants indeed employed such a strategy, they would be tuned to process the response-associated feature at the attended location, irrespective of whether this feature was relevant or irrelevant to the task on any given trial. Three main reasons incline us to reject this alternative account. First, in both Experiments 2 and 3 compatibility effects were much larger for the relevant than for the irrelevant dimension of the foil—a finding that is incompatible with the notion that participants ignored the task cue. Second, the two-dimension analysis in Experiments 2 and 3 replicated the findings of Experiment 1, namely, the foil's irrelevant dimension did not produce a compatibility effect—which should have occurred, had participants ignored the task cue. Third, a between-experiments analysis revealed that performance on two-dimension target trials was similar in Experiments 2 and 3 (in which these made up only 20% of all trials) and in Experiment 1 (in which they made up 100% of all trials), both in response times and in accuracy, both $ps > .30$. Had participants ignored the task cue, they would have had to randomly select one out of the two possible response features of the target in Experiments 2 and 3. As a result, their performance should have been substantially impaired relative to when they prepared for the task in advance (in Experiment 1).

Finally, it should be noted that the irrelevant dimension of the foil was relevant on half of the trials, such that in the context of the whole experiment, the foil's irrelevant dimension was in fact relevant. This situation arose because relations of compatibility in our study were arbitrary (as they were in the Cohen & Shoup, 1997 and Remington & Folk, 2001 studies) rather than semantic (as in color Stroop experiments, e.g., Kahneman & Chajczyk, 1983) and so in order to measure compatibility effects on an irrelevant dimension, it was necessary for the features on this dimension to be also associated with responses. It would therefore be important to determine in future research whether our findings generalize to paradigms in which the irrelevant dimension is never relevant.

Yet, if such relevance was critical for our findings of compatibility effects from a distractor's irrelevant dimension, it is more likely to reflect relevance *over the experiment* rather than carryover effects from a previous trial in which that dimension was relevant. Indeed, we found no solid evidence that compatibility effects were influenced by task repetition versus switch (i.e., by whether the irrelevant dimension on the current trial was irrelevant vs. relevant on the previous trial).[5]

Conclusion

Our findings suggest that all the features of an attended object are granted access to response control mechanisms, but features on the currently relevant dimension are granted more weight than currently irrelevant features. This description provides a parsimonious account of the findings from the extant literature and obviates the need to postulate a qualitative distinction between attention and selection for action (Lachter et al., 2009; Remington & Folk, 2001).

[4] We sampled six experiments from the literature, in which (a) as in our study, the task-relevant dimension was either letter identity (Atmaca, Sebanz, & Knoblich, 2011; Diedrichsen, Ivry, Cohen, & Danziger, 2000; Grice & Gwynne, 1985) or orientation (Cohen & Shoup, 1997); and (b) compatibility effects when the compatible flanker was perceptually similar versus dissimilar relative to the target were compared. In these studies, the size of the compatibility effect when the compatible flanker was perceptually dissimilar from the target was in the range of 55% to 80% (M = 70.5%, SE = 2.4%) of the effect's size when the compatible flanker was similar to the target.

[5] We examined whether the compatibility effect from the irrelevant dimension was enhanced when the task switched and reduced when the task repeated (and vice versa for the relevant dimension), as would be expected if relevance weights carried over to the subsequent trial. These analyses yielded inconsistent trends across experiments. A possible explanation is that intertrial effects can be very complex when a multitude of the task/display aspects can change independently from one trial to the next, as was the case in our experiments (see, e.g., Hommel, 1998, 2004, for examples of how repetitions of multiple features interact). Therefore, analyzing the effect of one type of repetition while ignoring others may distort the results—and running the complete analysis was not viable because the resulting number of trials in each cell was too small. Alterna-

tively, preparation time prior to the task display may have weakened possible sequential effects.

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