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Control of attention by a peripheral visual cue depends on whether the target is difficult to discriminate

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Abstract

The influence of a peripheral cue represented by a gray ring on responsivity to a subsequent target varies. When a vertical line inside a ring was a go target and a white small ring inside a ring was a no-go target, reaction time was shorter at the same location relative to a different location. However, no reaction time difference between the two locations occurred when a white cross inside the ring, instead of the white vertical line inside the ring, was the go target. We investigated whether this last finding was due to a forward masking influence of the cue, a requirement of low attention for the discrimination or a lack of attention mobilization by the cue. In Experiment 1, the intensity of the cue was reduced in an attempt to reduce forward masking. In Experiment 2, the vertical line and the cross were presented in the same block of trials so as to be dealt with a common attentional strategy. In Experiments 3 and 4, the no-go target was a 45º rotated cross inside a ring to increase the difficulty of the discrimination. No evidence was obtained that the cross was forward masked by the cue nor that it demanded less attention to be discriminated from the small ring. There was a facilitation of responsivity by the cue when the small ring was replaced by the rotated cross. The results suggest that when the discrimination to be performed is too easy the cue does not mobilize attention.

Key words
- Attention
- Cue
- Discriminability
- Strategy
- Masking

Introduction

That a peripheral visual cue affects reaction time to a visual target appearing next has been shown many times. When the interval between the onset of the two stimuli is of the order of 100 ms, reaction time is reduced at the same location as the cue and increased at distant locations (1). These effects are usually ascribed to the automatic attentional influence exerted by the cue. This is believed to improve sensory processing at the cue location and nearby region and to reduce its efficiency at distant locations (see Ref. 2).

Considering the automatic nature of attention mobilization by the peripheral cue, it is possible to imagine that its effects would be very consistent for different experimental situations. In fact, this does not happen. In some experimental situations the attentional effect (difference between reaction time in a different location condition and reaction time in the same location condition) amounts to several tens of milliseconds (e.g., Ref. 3, Experiment 2). In others it is less than 10 ms (e.g., Ref. 4, Experiment 1). In still others, it is simply absent (e.g., Ref. 5, Experiments 1 and 2).

This variability of the attentional effect has been related to the degree of mobilization of attention by the cue. Evidence accumulated over the last 15 years suggests that different attentional strategies are adopted in different experimental situations. Folk and collaborators (6,7; see also Ref. 8) were the first to demonstrate that the ability of the cue to influence performance changes as a function of its similarity to the target along some dimension. Thus, invalid abrupt-onset cues produce costs for targets characterized by an abrupt onset but not for targets characterized by a discontinuity in color, and, conversely, invalid color cues produce greater costs for color targets than for abrupt-onset targets. Onset and motion properties of the stimuli are apparently not distinguished by the organism. An onset cue produces the attentional effect for an onset target and also for a motion target, and a motion cue produces the attentional effect for a motion target and also for an onset target. Later, the same investigators reported more selective attentional effects. A red cue was shown to produce an attentional effect for a red target but not for a green target, and, vice versa, a green cue produces an attentional effect for a green target but not for a red target (9). The authors proposed what they called the "contingent involuntary orienting hypothesis". According to this hypothesis, attention is mobilized by a cue as long as this cue has the property that is critical for defining the target. In some non-specified way, attentional mechanisms would be tuned to the target defining characteristic, and, as a consequence, would be sensitized to cues with the same characteristic. Findings similar to those of Folk and collaborators were reported by other investigators (10-12), who interpreted them as supporting the contingent involuntary orienting hypothesis.

The attentional strategy used by the volunteers would also depend on the nature of the task, i.e., whether it involves stimulus detection or discrimination. Discrimination tasks tend to produce larger attentional effects than detection tasks. Lupiáñez et al. (4) reported values above 20 ms for the former tasks and below 20 ms for the latter. Previous experience matters. The strategy normally used in any one of these tasks could change if a task were performed after the other. Squella and Ribeiro-do-Valle (5) showed that the attentional effect produced by a gray ring in a go/no-go reaction time task when a white vertical line inside a ring was the positive target could completely disappear if the volunteers were previously tested with the same stimuli in a simple reaction time task. The exact mechanism of these attentional strategies is not clear.

A review of the available experimental results indicating an important endogenous modulation of automatic attention mobilization was recently published by Ruz and Lupiáñez (13).

In addition to the use of different attentional strategies, at least two other factors could theoretically contribute to the variability of the effect of the cue. One of these factors is the difficulty of the discrimination to be performed. The easier the discrimination of the targets, the less its attention dependence and the smaller the effect of the cue. Lee et al. (14) demonstrated that the discrimination of some targets could be performed in the near absence of attention.

The other factor is the potential forward masking action of the cue. This would produce some inhibition of sensory processing at the stimulated region and surroundings (15), that would counteract the attentional facilitation. As forward masking depends on the physical characteristics of both the cue and target and on the time interval separating these stimuli (see Ref. 16), its intensity could change in different stimulatory settings. The attentional effect would vary inversely with forward masking intensity. If this process becomes too intense, then an inverted effect could even appear. Reaction time would be longer at the cued location than at the other locations tested. Lambert and Hockey (17), Efron and Yund (18), and Squella and Ribeiro-do-Valle (5) considered the inverted effect produced by their cue to be due to just such a (strong) forward masking influence (see also Ref. 19).

In a previous study from this laboratory using a go/no-go task, it was observed that a peripheral cue, represented by a gray ring, had the expected influence on the reaction time to a go target, represented by a white vertical or horizontal line inside a ring, occurring 100 ms later. When this stimulus occurred at the same location as the cue, reaction time was shorter than when the stimulus occurred at a different location (20). In the same study, however, no effect was observed using the same cue, when a go target represented by a white cross inside the ring was used. While the adoption by the volunteers of a specific attentional strategy for discriminating each of these targets could be the explanation for this unexpected difference, a distinct dependence on attention for discriminating these targets or a distinct forward masking action of the cue on these targets should also be considered. The present study investigated these three possibilities.

Four experiments were done. In the first, the forward masking hypothesis was specifically examined. The results obtained did not support this hypothesis. The second experiment tested the attentional strategy hypothesis against both the forward masking and the low dependence on attention hypotheses. Its results, as well as those of the third and fourth experiments, fully support the attentional strategy hypothesis.

The Ethics Committee of Instituto de Ciências Biomédicas, Universidade de São Paulo, approved this study. Written informed consent was obtained from all participants.

Experiment 1

Azevedo et al. (20) attributed the absence of any attentional effect of their cue for the cross inside the ring to a forward masking process that would have neutralized the influence of attention. This hypothesis was based on the fact that reaction time to the cross inside the ring at the same location as the cue was longer than reaction time to the vertical line inside the ring at the same location, while reaction time to the cross inside the ring at a different location was not significantly different from reaction time to the vertical line inside the ring at a different location. The results of two other experiments from this laboratory (21,22), in which the stimuli were presented centrally instead of peripherally and the cue was absent in half of the trials (everything else was performed exactly as in Experiment 3 of the study of Azevedo et al., 20), further reinforced the idea that the cross inside the ring, but not the vertical line inside the ring, would be forward masked by the cue. In these experiments the cue produced an inhibitory effect when the cross inside the ring was the target but no effect at all when the vertical line inside the ring was the target.

Keysers and Perrett (23) suggested that masking (including forward masking) involves a competition between the neural representation of the masking stimulus and the neural representation of the target stimulus. It is reasonable to suppose that the competition between the neural representation of the cue and that of the target stimulus is more disturbing for more complex stimuli. In this case the complexity of the cross inside the ring as compared to that of the vertical line inside the ring would explain why it would have been selectively forward masked by the cue.

The present experiment directly tested the contribution of forward masking in the findings of Azevedo et al. (20). The intensity of the cue was more than halved in an attempt to reduce its putative forward masking action. This should lead to the expression of the opposite attentional influence of the cue, as observed by Lambert and Hockey (17) when they replaced their high intensity cue with a low intensity one.

Methods

Participants. Twelve young female adults voluntarily participated in the experiment. All were right handed and had normal or corrected-to-normal vision. None of them had previous experience with reaction time tasks or was aware of the purpose of the study.

Apparatus. The volunteers were tested in a dimly illuminated (<0.1 cd/m^2) and sound-attenuated room. Their head was spatially positioned by a chin-and-front rest so that their eyes were 57 cm away from the screen of a 17-inch video monitor. The background luminance of this screen was less than 0.01 cd/m^2. A central white 0.05-degree wide square (fixation point, FP) and peripheral visual stimuli were presented on this screen. The volunteers were instructed to keep their eyes on the FP and to respond to some of these peripheral stimuli by pressing a key with their right index finger. An IBM-compatible computer controlled by programs developed with the MEL2 software (Psychology Software Tools Inc., Pittsburgh, PA, USA), generated the stimuli and recorded the responses.

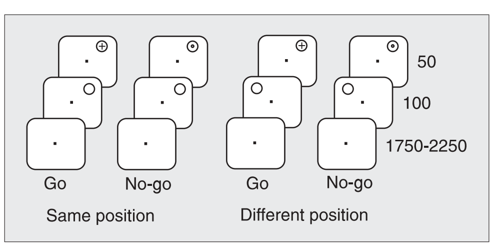

Figure 1. Illustration of four trial sequences (two go trials and two no-go trials). The fixation display appears first, followed by the cue display and finally the target display. The cue was gray and the targets were white. Background was black. Numbers on the right side of the figure refer to the duration (in milliseconds) of each display.

Procedure. Each volunteer participated in two testing sessions on different days (not more than seven days apart). Before each session the volunteer received a brief written explanation regarding the test. A more detailed explanation was given in the testing room while the volunteer was performing some trial examples. The volunteer was then asked to perform about 20 practice trials.

The main purpose of the first testing session was the familiarization of the volunteers with the experimental conditions. It consisted of four blocks of 64 trials each. Between one block and the next there was a short resting interval. Each trial began with the appearance of the FP. After 1850 to 2350 ms, a target appeared. In the first two blocks or the second two blocks, the targets were a vertical line (0.96 degree long and 0.10 degree wide) inside a ring (1.72 degree in diameter and a 0.05-degree wide margin) and a ring (0.29 degree in diameter and a 0.05-degree wide margin) inside a ring (1.72 degree in diameter and a 0.05-degree wide margin). In the other two blocks, the targets were a cross (each arm 0.96 degree long and 0.05 degree wide) inside a ring (1.72 degree in diameter and a 0.05-degree wide margin) and a ring inside the ring. All these stimuli were white and had a luminance of 25.8 cd/m^2. They lasted 50 ms. They could occur in any one of the four corners of a virtual square centered on the FP, 8 degree from this FP (see Figure 1). In each block, one of the targets appeared in half of the trials and the other in the other half, randomly. The volunteer was instructed to respond as fast as possible to the “vertical line inside the ring” or to the “cross inside the ring” (herein called the S2+) and not to respond to the “small ring inside the ring” (herein called the S2-). The trial ended with a message lasting 200 ms at the site of fixation. Reaction time in milliseconds appeared when the volunteer responded between 150 and 600 ms after the onset of the S2+. The message “anticipated” or “slow” was displayed when she emitted a response before 150 ms after the onset of the S2+/S2- and did not respond until 600 ms after the onset of the S2+, respectively. The message "incorrect" was displayed when the volunteer responded between 150 and 600 ms after the onset of the S2-. Error trials were repeated.

The second testing session was similar to the first but the trials now included another stimulus represented by a gray ring (1.72 degree in diameter and a 0.05-degree wide margin), 2.6 cd/m^2 bright and 100 ms long (herein called the S1). The offset of this stimulus was immediately succeeded by the onset of the target, that occurred at the same location in half of the trials and at a different horizontal location in the other half of the trials, in a random way.

The order of testing with the two S2+ was balanced between the volunteers. For any given volunteer the same order was followed in the two testing sessions.

Data analysis

For each volunteer the block median reaction time was calculated and then the mean of the two medians for each condition for each session was calculated. The total number of anticipated responses, slow responses and commission responses (false alarms) for each condition of the second session was also evaluated.

Reaction time to the vertical line in the first session was compared to reaction time to the cross in the same session by means of the *t*-test for dependent samples. Reaction time data of the second session were treated by repeated measures analysis of variance (ANOVA) and the *post hoc* Newman-Keuls test. Factors in the ANOVA were type of positive target and relative location of cue and target. The level of significance was set at 0.05.

The data analysis just described was used also in the other experiments of the present study.

Results and Discussion

In the first testing session, reaction time to the vertical line did not differ from that to the cross ($t(11) = 1.304$, $P = 0.219$; see Figure 2).

In the second testing session, a main effect of location ($F(1,11) = 6.705$, $P = 0.025$) and an interaction between target and location ($F(1,11) = 22.645$, $P < 0.001$) were observed. There was no main effect of target ($F(1,11) = 0.480$, $P = 0.503$). Reaction time to the vertical line at the same location as the S1 was shorter than that to the same stimulus at the different location than the S1 ($P < 0.001$). Reaction times to the cross at the two locations did not differ ($P = 0.614$). Reaction times to the cross at the same location and at the different location were longer than that to the vertical line at the same location ($P = 0.030$ in both cases) and shorter than that to the vertical line at the different location ($P = 0.002$ in both cases) (see Figure 2).

The percentages of anticipation, omission and commission errors in the second testing session were 0.7, 2.7, and 5.7, respectively.

The conspicuous attentional effect observed for the vertical line (37 ms) demonstrates that the cue mobilized attention efficiently despite its low luminance. In fact, the magnitude of this attentional effect was in the range of values obtained in other experiments from this laboratory with a higher intensity (more exactly, 5.8 cd/m^2) cue,

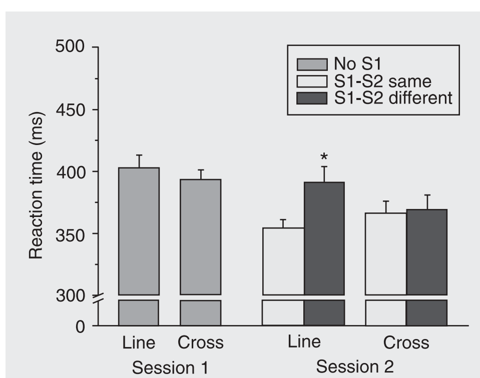

Figure 2. Mean reaction time (± SEM) to the vertical line inside the ring and to the cross inside the ring in Experiment 1. The negative target was the small ring inside the ring. In the first testing session, only the targets occurred. In the second testing session, a peripheral cue appeared 100 ms before the target, in the same location or in a different location. The vertical line inside the ring and the cross inside the ring occurred in separate blocks. N = 12. *P < 0.001 for the comparison between the conditions cue and vertical line in the same location and cue and vertical line in different locations (Newman-Keuls test).

namely 20 to 60 ms (20).

The reduction of the intensity of the cue should have decreased any forward masking action that the cue might exert. An attentional influence of the cue on the central processing of the cross, less antagonized than before, should have become apparent. The continued absence of any effect observed for this target indicates that a forward masking competition with attention is probably not the appropriate explanation for the finding.

It should be noted that reaction times to the cross in the same position and different position conditions, in addition to being similar, were longer than reaction time to the vertical line in the same position condition but shorter than reaction time to the vertical line in the different position condition. This suggests that the cue was exerting no influence at all on the identification of the cross (results obtained in an unpublished experiment from this laboratory, in which the cue was not presented in either testing session, suggest that the shorter reaction time to the vertical line and the cross in the second session was simply due to familiarization with the task). The discrimination of the cross from the small ring might have been so easy that it could be performed with some residual diffuse attention left after the cue or, alternatively, the strategy of mobilizing less attention to the cue might have been adopted when this positive target was used.

Experiment 2

The attentional strategy hypothesis can be contrasted to the two other hypotheses raised to explain the distinct results obtained in this laboratory with the vertical line inside the ring and the cross inside the ring. In the experiments reported by Azevedo et al. (20) as well as in Experiment 1 in the present study these two targets were presented in separate blocks of trials. This may have allowed the participants to develop a particular attentional strategy for each kind of block. More specifically, their attention could have been controlled by the cue in the blocks in which the vertical line inside the ring was the target, but not in the blocks in which the cross inside the ring was the target.

The attentional strategy hypothesis predicts similar effects of the cue for the two targets if they were mixed in the same block of trials, since in this situation presumably just one strategy would be used by the participants to deal with the cue. Either the “vertical line attentional strategy” or the “cross attentional strategy” or some attentional strategy intermediate between these two could be used. The particular strategy chosen would give some clue about the factor dominating attention control. If the cue-target similarity factor is as important as suggested in the literature (and if the ring that represents the cue can be considered to have some physical resemblance in shape to the vertical line inside the ring), at least some attentional effect should be observed.

Methods

Participants. Thirteen other female volunteers with the characteristics described in Experiment 1 were used.

Procedure. The volunteers were tested as described in Experiment 1, with two exceptions. First, the cue had a luminance of 5.8 cd/m^2. Second, both S2+, that is, the vertical line inside the ring and the cross inside the ring, were presented in each of the four blocks of the sessions. Each S2+ occurred in 25% of the trials of the block and the S2-, represented by the ring inside the ring, occurred in the remaining 50% of the trials of the block. These stimuli occurred at random.

Results and Discussion

In the first testing session reaction time to the cross was shorter than reaction time to the vertical line (t(12) = 2.724, P = 0.018; see Figure 3).

In the second testing session, a main effect of target (F(1,12) = 27.807, P < 0.001) was observed. Reaction time to the cross was shorter than that to the vertical line. There was no main effect of location (F(1,12) = 0.004, P = 0.952) and no interaction between the target and the location factors (F(1,12) = 0.934, P = 0.353; see Figure 3).

The percentages of anticipation, omission and commission errors in the second testing session were 0.3, 3.0, and 5.8, respectively.

No attentional effect occurred for the vertical line or the cross. This can be interpreted as an indication that the cue did not mobilize attention. The participants would have adopted the attentional strategy normally used when only the cross had to be discriminated from the small ring.

The shorter reaction time to the cross than to the vertical line in both the first and the second testing sessions indicates that the former stimulus was more easily distinguished from the small ring than the latter stimulus. One should consider the interesting possibility that the discriminability of the positive target is a critical factor determining the selection of the attentional strategy used to deal with the cue. When at least one positive target is highly discriminable, the cue would not be able to control attention.

Lupiáñez et al. (4) and Squella and Ribeiro-do-Valle (5) suggested that the duration and the magnitude of the attentional influence of a cue are directly related to the degree of difficulty of the task being performed. The task of discriminating the vertical line and the cross from the small ring in the same block of trials was certainly more difficult than that of discriminating each of these positive targets in turn from the small ring. The longer reaction times observed in this experiment as compared to those observed, for example, in Experiment 1 are proof of this. The absence of any attentional effect in the present experiment, while a large and robust attentional effect occurred in the easier task of discriminating the vertical line from the small ring, suggests that the degree of difficulty of the task is not as decisive for attention mobilization by a cue as Lupiáñez et al. (4) and Squella and Ribeiro-do-Valle (5) imagined.

As the same attentional strategy was presumably used for both the vertical line and the cross in the second testing session of this experiment, any differential forward masking influence of the cue on these targets or differential dependence on attention for identification of these targets that might exist should have become apparent. The observed shorter reaction time to the cross than to the vertical line at the same location argues against the idea that the former stimulus but not the latter is forward masked by the cue, corroborating the conclusion of Experiment 1. The absence of any difference between reaction time at the same location and reaction time at the different location for both the cross and the vertical line does not support the idea that the latter stimulus demands more attention for its identification than the former.

The importance of a similarity between the cue and the target for attention control by that stimulus could not be confirmed.

Experiment 3

If the discriminability of the cross inside

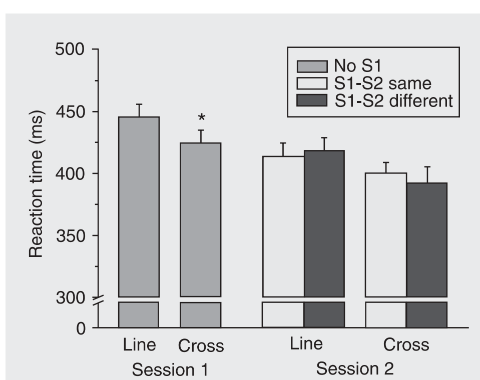

Figure 3. Mean reaction time (± SEM) to the vertical line inside the ring and to the cross inside the ring in Experiment 2. The negative target was the small ring inside the ring. In the first testing session, only the targets occurred. In the second testing session, a peripheral cue appeared 100 ms before the target, in the same location or in a different location. The vertical line inside the ring and the cross inside the ring occurred in the same blocks. N = 13. *P = 0.018 for the comparison between the conditions vertical line and cross (Newman-Keuls test).

the ring was critical for the cue being ignored in the study of Azevedo et al. (20) and in Experiments 1 and 2 of the present study, as considered above, very different results should be obtained by reducing it.

In the present experiment, the discriminability of the cross inside the ring was decreased by using a negative target more similar to it than the small ring inside the ring. According to the hypothesis being considered, there ought to occur a significant mobilization of attention by the cue, leading this stimulus to cause a significant attentional effect.

Methods

Participants. Three male and 10 other female volunteers with the characteristics described in Experiment 1 were used.

Procedure. The volunteers were tested as described in Experiment 1, with two exceptions. First, the cue had a luminance of 5.8 cd/m^2. Second, a 45º rotated cross (each arm 0.96 degree long and 0.05 degree wide) inside a ring (1.72 degree in diameter and a 0.05-degree wide margin) was used as the negative target instead of the ring inside the ring.

Results and Discussion

In the first testing session, reaction time to the cross was much longer than that to the vertical line ($t(12) = -10.894$, $P < 0.001$; see Figure 4).

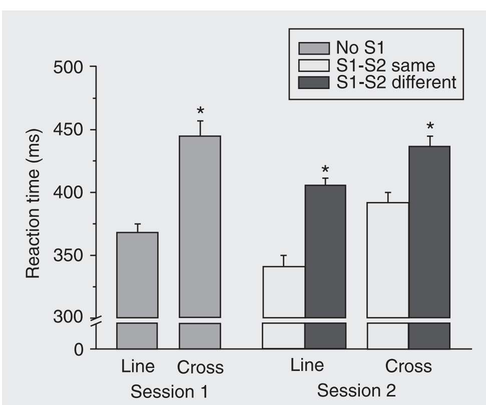

Figure 4. Mean reaction time (± SEM) to the vertical line inside the ring and to the cross inside the ring in Experiment 3. The negative target was the 45º rotated cross inside the ring. In the first testing session, only the targets occurred. In the second testing session, a peripheral cue appeared 100 ms before the target, in the same location or in a different location. The vertical line inside the ring and the cross inside the ring occurred in separate blocks. N = 13. *P < 0.001 for the comparisons between the conditions vertical line and cross, between the conditions cue and vertical line in the same location and cue and vertical line in different locations, and between the conditions cue and cross in the same location and cue and cross in different locations (Newman-Keuls test).

In the second testing session, a main effect of target ($F(1,12) = 53.160$, $P < 0.001$), of location ($F(1,12) = 62.938$, $P < 0.001$) and an interaction between these two factors ($F(1,12) = 5.319$, $P < 0.040$) were observed. Reaction time to the vertical line at a different location than S1 was longer than that at the same location as S1 ($P < 0.001$). In the same way, reaction time to the cross at a different location was longer than that at the same location ($P < 0.001$). Reaction time to the cross at the same location was longer than that to the vertical line at the same location ($P < 0.001$), and reaction time to the cross at the different location was longer than that to the vertical line at the different location ($P < 0.001$; see Figure 4).

The percentages of anticipation, omission and commission errors in the second testing session were 0.6, 5.3, and 8.2, respectively.

The much longer reaction time to the cross than to the vertical line in the first testing session clearly shows that discriminating the cross from the rotated cross was more difficult than discriminating the vertical line from this last stimulus.

The large attentional effect (61 ms) observed for the vertical line in the second testing session indicates a strong mobilization of attention by the cue. It is significant that an important attentional effect (40 ms) was also obtained for the cross. This last finding supports the hypothesis that previous results obtained with this stimulus were due to its high discriminability in the stimulatory setting. By simply reducing this discriminability, the expected attentional effect appeared.

The results of the present experiment argue against the possibility that the attentional effects observed in the study of Azevedo et al. (20) and in Experiment 1 in the present study for the vertical line were related to some physical similarity in shape between the cue and this target, as might be supposed considering, for example, the findings of Folk and Remington (9) and Cheal and Chastain (11). If this were the case, an attentional effect should only have been observed for the vertical line again, and not for the cross.

Experiment 4

The absence of any attentional effect of the cue in Experiment 2, in which the two positive targets were mixed in the blocks, was related to the high discriminability of the cross inside the ring. Another possibility, however, might be that the strategy adopted by the participants to deal with the cue was in fact a consequence of the existence of three targets, the two positive ones and the negative one, in these blocks. Processing of the cue could have been suppressed as a way of making the task easier to perform.

In this experiment the vertical line inside the ring and the cross inside the ring were again mixed in each block of trials but the rotated cross inside the ring was used as a negative target. If the strategy used to deal with the cue is selected on the basis of the discriminability of the target, as proposed, the expectation in this experiment was the occurrence of an attentional effect since, presumably, neither target was highly discriminable. This effect should appear for both targets and, in addition, should be similar for both of them since only one attentional strategy would probably be used during a block of trials.

Methods

Participants. Twelve other female volunteers with the characteristics described in Experiment 1 were used.

Procedure. The volunteers were tested as described in Experiment 1, with three exceptions. First, the cue had a luminance of 5.8 cd/m^2. Second, the S2- was the 45° rotated cross inside the ring used in Experiment 3. Third, both S2+, that is, the vertical line inside the ring and the cross inside the ring, were presented in each of the four blocks of the sessions. Each S2+ occurred in 25% of the trials of the block and the S2- occurred in the remaining 50% of the trials of the block. These stimuli occurred at random.

Results and Discussion

In the first testing session, reaction time to the cross was much longer than that to the vertical line (t(11) = -6.488, P < 0.001; see Figure 5).

In the second testing session, a main effect of target (F(1,11) = 74.398, P < 0.001) and of location (F(1,11) = 26.767, P < 0.001) was observed. There was no interaction between these two factors (F(1,11) = 0.547, P = 0.475). Reaction time to the cross was longer than that to the vertical line. Reaction time to the target at a different location than the S1 was longer than that at the same location as the S1 (P < 0.001; see Figure 5).

The percentages of anticipation, omission and commission errors in the second testing session were 0.35, 10.0, and 12.0, respectively.

As predicted, there was an attentional effect for both the vertical line and the cross, and these effects were very similar (27 ms for the vertical line and 33 ms for the cross).

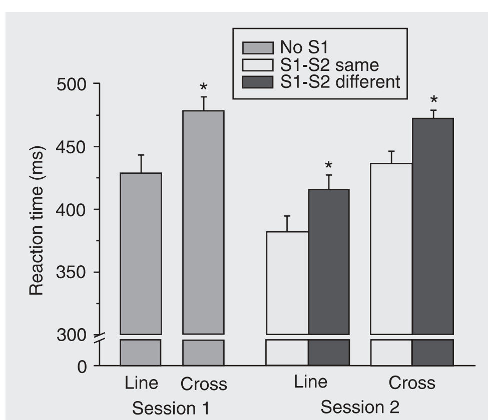

Figure 5. Mean reaction time (± SEM) to the vertical line inside the ring and to the cross inside the ring in Experiment 4. The negative target was the 45° rotated cross inside the ring. In the first testing session, only the targets occurred. In the second testing session, a peripheral cue appeared 100 ms before the target, in the same location or in a different location. The vertical line inside the ring and the cross inside the ring occurred in the same blocks. N = 12. *P < 0.001 for the comparisons between the conditions vertical line and cross, between the conditions cue and vertical line in the same location and cue and vertical line in different locations, and between the conditions cue and cross in the same location and cue and cross in different locations (Newman-Keuls test).

These findings demonstrate that it was not the presence of three targets in the same block of trials that caused the complete disappearance of attentional effects in Experiment 2. They corroborate the hypothesis that the strategy adopted to deal with the cue is related to the discriminability of the (positive) target. As the discriminability of both positive targets was presumably low here, the cue became capable of controlling attention and, thus, of influencing the identification of the target.

The magnitudes of the attentional effects obtained here were not higher than those of the attentional effects of the previous experiment, despite the obvious greater task difficulty (as indicated by the longer reaction times). This observation can be considered as further evidence against the idea that the mobilization of attention by a cue is influenced to a significant extent by task difficulty.

General Discussion

The present study demonstrated that the occurrence of an attentional effect of a peripheral cue in a go/no-go task is critically dependent on the particular features of the targets. When the positive target is a vertical line inside a ring and the negative target is a ring inside a ring or a rotated cross inside a ring, or the positive target is a cross inside a ring and the negative target is a rotated cross inside a ring the attentional effect occurs. No effect occurs, however, when the positive target is the cross inside the ring and the negative target is the ring inside the ring. These observations can be interpreted as indicating that distinct attentional strategies are used in the two cases. In the former situation the peripheral cue would produce a central signal strong enough to activate the attentional circuits, and in the latter situation this central signal would be too weak to activate these circuits. The enhancement of the occipital N1 wave elicited by a peripheral visual cue in blocks of trials in which an attentional effect occurred but not in those in which this effect did not occur, in the study of Arnott et al. (10), is certainly in accordance with these ideas.

There is abundant evidence in the literature that the cue can be dealt with in different ways depending on the defining attributes of the target (6,7,9-12,24). It is commonly assumed that a critical factor determining the choice of a particular strategy is the degree of similarity between the cue and the target. Cues that resemble more closely the target would tend to control attention. One reason for this could be that these cues generate a relatively strong central signal because their neural representation is maintained tonically facilitated during the testing session together with the partially superposed target neural representation.

This hypothesis for attention control by a cue would explain reasonably well the findings of Azevedo et al. (20) and those of Experiment 1 in the present study if the gray ring (the cue) is assumed to be somewhat physically similar in shape to the white vertical line inside the ring but not to the white cross inside the ring (the go targets). It does not account so well, however, for the different findings of Experiments 2 and 4 (absence of any attentional effect and presence of a general attentional effect, respectively), and, especially, for the attentional effect observed for the cross inside the ring when the rotated cross inside the ring was the negative target in Experiment 3. The cue signal should not become more similar to the cross inside the ring signal as a consequence of the small ring inside the ring being replaced by the rotated cross inside the ring.

The results of Experiments 2, 3 and 4 of the present study suggest that, more important than cue-target similarity in attentional strategy choice is the discriminability of the positive target in the stimulatory setting. A more discriminable positive target would have a more individualized neural representation that could remain selectively facilitated during performance of the task. The other neural representations, including that of the cue, would not be facilitated and might even be inhibited. The cue would not generate a strong enough signal to activate the attentional circuits. Differently, a less discriminable positive target would have a neural representation at least partially superposed on those of the other stimuli. Not only its neural representation, but also those of these other stimuli, would remain facilitated by attention. The cue would now be processed to the point of being able to further activate the attentional circuits.

The main difference between the target discriminability hypothesis and the cue similarity hypothesis is that the former takes into account the influence of other stimuli besides the cue and the target. The target discriminability hypothesis can be considered to be an expanded version of the cue similarity hypothesis.

In the studies of Folk et al. (6,7), Folk and Remington (9), Arnott et al. (10), Cheal and Chastain (11), and Lambert et al. (12), the target was always presented among distractors. This should have considerably reduced its discriminability compared to conditions where it occurs alone, as in the present study. There should have been a tonic facilitation of the neural representation of the target and also, to a certain extent, of the other stimuli presented, including the cue. Presumably this facilitation was more significant for cues that were similar in some dimension to the target since their neural representations would partially superpose that of this stimulus. It is no surprise, then, that these similar cues proved to be more capable to control attention. The same line of reasoning could be used to explain the influence of the similarity between the cue and the target context on the ability of this cue to control attention, as reported by Gibson and Kelsey (25) and Atchley et al. (24).

A strong concurrent of the target discriminability hypothesis is what could be called the task difficulty hypothesis. According to the latter, attention mobilization by a cue would be related to the difficulty of the task (4,5). As the difficulty of the discrimination increases more attention would be dedicated to the task, tonically facilitating not only central processing of the targets but also that of the cue. This would render the cue more apt to control attention automatically. However, the results of Experiments 2, 3, and 4 argue against this alternative hypothesis. There was no attentional effect in Experiment 2, where the volunteers had to discriminate between three targets (certainly a more difficult task than to discriminate between two targets). In the same way, the attentional effect in Experiment 3 was smaller, instead of larger, for the more difficult discrimination between the cross and the rotated cross, and the attentional effect in Experiment 4, in which in addition to discriminating three targets the volunteers had to discriminate the cross from the rotated cross, was not particularly large. Results reported by Cheal and Lyon (26) also indicate that task difficulty does not influence the extent to which attention is mobilized by a cue. Thus, despite its intuitive appeal, the task difficulty hypothesis does not appear to be appropriate.

The variable influence of a peripheral visual cue in stimulatory settings where no distractors are presented together with the target has not been systematically investigated. Most published studies report a significant attentional effect, leading others to believe that this is the most common finding. Perhaps the opposite is true, especially when one uses a simple reaction time task to test the volunteers (see Ref. 27).

The findings of the present study demonstrate that by comparing the stimulatory conditions that lead to the appearance of the attentional effect and that do not lead to the appearance of this effect one can obtain important clues about the mechanisms responsible for automatic attention control. Automatic attention would most likely be mobilized by sensory stimuli that are relevant for the individual or that, although mostly irrelevant, are significantly processed by the central nervous system when working in a low selectivity mode. This conclusion is obviously meant to apply not only to behavior in experimental situations, like those used here, but also to behavior in real life situations.

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