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Priming effects of a peripheral visual stimulus in simple and go/no-go tasks

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Abstract

The early facilitatory effect of a peripheral spatially visual prime stimulus described in the literature for simple reaction time tasks has been usually smaller than that described for complex (go/no-go, choice) reaction time tasks. In the present study we investigated the reason for this difference. In a first and a second experiment we tested the participants in both a simple task and a go/no-go task, half of them beginning with one of these tasks and half with the other one. We observed that the prime stimulus had an early effect, inhibitory for the simple task and facilitatory for the go/no-go task, when the task was performed first. No early effect appeared when the task was performed second. In a third and a fourth experiment the participants were, respectively, tested in the simple task and in the go/no-go task for four sessions (the prime stimulus was presented in the second, third and fourth sessions). The early effects of the prime stimulus did not change across the sessions, suggesting that a habituatory process was not the cause for the disappearance of these effects in the first two experiments. Our findings are compatible with the idea that different attentional strategies are adopted in simple and complex reaction time tasks. In the former tasks the gain of automatic attention mechanisms may be adjusted to a low level and in the latter tasks, to a high level. The attentional influence of the prime stimulus may be antagonized by another influence, possibly a masking one.

Key words
- Priming
- Attention
- Masking
- Simple task
- Go/no-go task

Introduction

Latency and accuracy of responding to a peripheral visual stimulus have been shown to be affected by the occurrence immediately before (50-150 ms) of another peripheral visual stimulus. Latency is reduced and accuracy increased when the target stimulus occurs at the same position as the prime stimulus as compared to when it occurs at a different position than the prime stimulus (1-5). This so-called "early facilitatory effect" of the prime stimulus has been related to the automatic orienting of attention to its position and away from other positions, respectively favoring and inhibiting the processing of subsequent stimuli there.

The early facilitatory effect of a prime stimulus reported for simple reaction time tasks has been usually smaller than that described for complex (go/no-go, choice) reaction time tasks. For example, Posner and Cohen (2), Maylor and Hockey (3), Lambert and Hockey (6) and Collie et al. (7), respectively, found effects of about 23 ms (Experiment 1, Figure 32.2), 23 ms (Experiment 1), about 10 and 18 ms (Experiments 1 and 2, Figures 1 and 2, initial blocks) and 12 and 19 ms (Experiment 3) in simple tasks. Jonides (1), Theeuwes (8), Henderson and Macquistan (9) and Azevedo et al. (10), respectively, obtained effects of 97 ms (Experiment 2), about 38 ms (Experiment 1), 22 ms (Experiment 3) and 57, 36 and 21 ms (Experiments 1, 3 and 4) in complex tasks. Trivial factors, like the particular stimulatory conditions or the particular individuals tested, could explain this difference.

Lupiáñez and collaborators reported effects of 21, 15, 20 and 22 ms (Experiments 1A, 2A, 3A and 4A; Ref. 11), 7 and 19 ms (Experiments 1 and 2; Ref. 12) and 13 ms (Experiment 1A; Ref. 13) for simple tasks and of 44, 38, 30 and 24 ms (Experiments 1B, 2B, 3B and 4B; Ref. 11), 26 and 39 ms (Experiments 1 and 2; Ref. 12) and 37 ms (Experiment 1; Ref. 13) for choice tasks. For a go/no-go task they reported an effect of 26 ms (Experiment 1; Ref. 13). Similarly, Pratt and McAuliffe (14) described effects of 19 ms (Experiment 2) and 43 ms (Experiment 1) for simple and choice tasks, respectively. The results reported by these two groups of investigators are very interesting because the same stimuli were used to test the participants in the simple and the complex tasks. Even in these studies, however, one cannot rule out the possibility that the different groups of participants performing the two types of tasks was the factor responsible for the results. Our experience has shown that the magnitude of the early facilitatory effect of the prime stimulus in a given experimental situation can change considerably from one group of participants to another.

The other cause for the difference in the early facilitatory effect of the prime stimulus could obviously be the nature of the task. There could be fewer processing stages for automatic attention to act upon in simple than in complex tasks or mechanisms less sensitive to automatic attention could mediate simple tasks as opposed to complex tasks. The idea that very different mechanisms mediate simple and complex tasks is certainly not new (for example, see Ref. 15). Also, automatic attention mechanisms could be set to operate at a lower gain level in simple tasks than in complex tasks as a consequence of the usual particular demands of these tasks. Evidence for an adjustment of automatic attention mechanisms to task demands was presented by Folk et al. (16,17). Finally, there could be less room for automatic attention to reduce reaction time in simple tasks than in complex tasks because of the greater previous preparation to process the target stimulus in the former tasks than in the latter ones (see 18).

In the present study, we determined whether the early facilitatory effect of a visual prime stimulus depends on the nature, simple or complex, of the task and observed that it does. Our results suggest that different attentional strategies are normally adopted by the organism for these two kinds of tasks.

This study was approved by the Ethics Committee of the Instituto de Ciências Biomédicas, Universidade de São Paulo, and informed consent was obtained from each volunteer.

Experiment 1

We compared the performance of the same volunteers in a simple and a go/no-go task. We used stimulatory conditions identical to those described in a previous study (10) to induce a robust early facilitatory effect in the go/no-go task. We expected that an early facilitatory effect would occur in both tasks, though smaller in the simple task than in the go/no-go task, and that this effect would be about the same whether the task is performed first or second.

Method

Participants. Twelve young male 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 were aware of the purpose of the study.

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

Procedure. Each volunteer participated in two testing sessions on separate days (not more than seven days apart). Before each session he/she received a brief written explanation about it. A more detailed explanation was given in the testing room while he/she was performing some example trials. The participant was then asked to perform about 20 additional practice trials.

The first testing session consisted of four blocks, each with 64 trials. There was a short resting interval between one block and the next.

Each trial began with the appearance of the fixation point. Between 1850 and 2350 ms later a target stimulus could appear. In the first two blocks or the second two blocks this stimulus was a vertical line (0.98 deg long and 0.05 deg wide) inside a ring (1.72 deg in diameter and a 0.05-deg wide margin). The stimulus appeared in half of the trials (32 trials x 2 blocks), while in the other half of the trials (32 trials x 2 blocks) there was no target stimulus. In the other two blocks the target stimulus could be either the vertical line inside the ring or a ring (0.29 deg in diameter and a 0.05-deg wide margin) inside a ring (1.72 deg in diameter and a 0.05-deg wide margin). Each of these stimuli appeared in half of the trials (32 trials x 2 blocks). All the stimuli were white and had a luminance of 25.8 cd/m^2. Their duration was 50 ms. They occurred in any one of the four corners of a virtual square centered on the fixation point, 8 deg from this fixation point. The participant was instructed to respond as fast as possible to the vertical line inside the ring (herein called S2 in the blocks in which this was the only target stimulus and S2+ in the blocks in which there was also the other target stimulus). The participant was instructed not to respond to the ring inside the ring (herein called the S2-) in the blocks in which this stimulus also appeared. The trial ended with a message lasting 200 ms at the site of fixation. Reaction time in milliseconds appeared on the screen when the participant responded between 150 and 600 ms after the onset of the S2/S2+. The message “anticipated” or “slow” was displayed when he/she emitted a response less than 150 ms after the onset of the S2/S2+/S2- and more than 600 ms after the onset of the S2/S2+, respectively. The message “incorrect” was displayed when the participant responded between 150 and 600 ms after the time when the S2 should have appeared or at the onset of the S2-. Error trials were repeated.

The second testing session was similar to the first. The trials now included another stimulus (S1), represented by a gray ring (1.72 deg in diameter and a 0.05-deg wide margin) with a luminance of 5.8 cd/m^2. In the two blocks in which there was only one target stimulus, the S1 preceded this stimulus in half of the trials (32 trials x 2 blocks) and occurred alone in the other half of the trials (32 trials x 2 blocks). This high percentage of catch trials was an attempt to make the simple task more comparable to the go/no-go task in terms of responding demand. In the two blocks in which there were two target stimuli, the S1 preceded each of these stimuli in half of the trials (32 trials x 2 blocks). Stimulus onset asynchrony was always 100 ms. The S2/S2+/S2- could occur equally at the same position as the S1 (16 trials x 2 blocks) or at a different (horizontally or vertically, but not diagonally) position than the S1 (16 trials x 2 blocks). In the same position condition the S1 disappeared with the appearance of the S2/S2+/S2-. In the different position condition it disappeared at the same time as the S2/S2+/S2-.

Half of the participants did the simple reaction time task first in the two testing sessions. The other half of the participants did the complex (go/no-go) reaction time task first in the two testing sessions.

Data analysis

The participants were divided into a group that performed the simple task before the go/no-go task (group S-G) and a group that performed the go/no-go task before the simple task (group G-S). The mean of the medians of the block reaction times for each condition was calculated for each participant. The number of anticipated responses, slow responses and incorrect responses in the second testing session for each condition was also recorded for each participant.

Reaction time data for the first and the second testing sessions were treated separately. These data were submitted to a repeated measures analysis of variance (ANOVA) having as factors the group and the task, in the case of the first testing session, and the group, the task and the S1-S2/S2+ relative position, in the case of the second testing session. When appropriate these data were further analyzed by the Newman-Keuls test.

Accuracy data (number of slow responses for the simple task, and number of undue responses and number of slow responses for the go/no-go task) corresponding to the two relative positions of the S1 and the S2/S2+/S2-, divided according to group and to task, were compared using the Wilcoxon test.

Significance levels of 0.05 and 0.01 were adopted for the reaction time data analysis and the accuracy data analysis, respectively. A more strict criterion was used for the accuracy data analysis because of the repeated comparisons performed.

Results and Discussion

For the first testing session there was no main effect of group ($F_{1,10}$ = 0.09, P = 0.8), no interaction between group and task ($F_{1,10}$ = 3.21, P = 0.1), and a main effect of task ($F_{1,10}$ = 86.33, P<0.001). Reaction time, as expected, was shorter for the simple task than for the go/no-go task (Table 1). The fact that performance in each task did not differ when the task was applied first or second is relevant, showing that these tasks do not necessarily interfere with each other.

For the second testing session there was no main effect of group ($F_{1,10}$<0.01, P>0.9) or of relative position of the stimuli ($F_{1,10}$ = 0.20, P = 0.7), and no interaction between group and task ($F_{1,10}$ = 0.40, P = 0.5), between group and relative position of the stimuli ($F_{1,10}$ = 2.02, P = 0.2) and between group, task and relative position of the stimuli ($F_{1,10}$ = 0.43, P = 0.5). There was a main effect of task ($F_{1,10}$ = 39.08, P<0.001) and an interaction between task and relative position of the stimuli ($F_{1,10}$ = 15.29, P = 0.003). As expected, reaction time was again shorter for the simple task than for the go/no-go task. Reaction time was longer when the S2 occurred at the same position as the S1 than when it occurred at a different position (P = 0.006) for the simple task (Table 1).

The data obtained for each group in the second testing session were submitted to an additional repeated measures ANOVA having as factors the task and the relative position of the S1 and the S2/S2+. For group S-G, there was no main effect of relative position of the stimuli ($F_{1,5}$ = 5.99, P = 0.06). There was a main effect of task ($F_{1,5}$ = 31.26, P = 0.003) and an interaction between task and relative position of the stimuli ($F_{1,5}$ = 7.64, P = 0.04). Reaction time was longer when the S2 appeared at the same position as the S1 than when it appeared at a different position (P = 0.01) for the simple task (Table 1). For group G-S, there was no main effect of relative position of the stimuli ($F_{1,5}$ = 0.28, P = 0.6). There was a main effect of task ($F_{1,5}$ = 12.71, P = 0.02) and an interaction between task and relative position of the stimuli ($F_{1,5}$ = 8.34, P = 0.03). Reaction time was shorter when the S2+ appeared at the same position as the S1 than when it appeared at a different position (P = 0.02) for the go/no-go task (Table 1).

In the second testing session the percents of anticipation, commission (responses in catch trials) and omission errors for the simple task were 1.4, 5.9 and 1.8%, respectively. For the go/no-go task the percents of anticipation, commission and omission errors were 0.7, 8.1 and 4.2%, respectively. No effect of the prime stimulus on accuracy was observed for either task, independently of whether a task was performed first or second.

The early inhibitory effect of 35 ms of the prime stimulus observed in the simple task when performed first was not anticipated. As mentioned before, an early facilitatory effect of the prime stimulus has usually been reported in this kind of task. There are a few descriptions in the literature of an early inhibitory effect of the prime stimulus in simple tasks. Lambert and Hockey (6) found an inhibitory effect of about 15 ms (Experiment 3, Figure 3b, initial blocks). Their prime stimulus was a large luminance increase of the outline of one of two 1.7 x 1.7-deg empty squares located on each side of the fixation point, that lasted 100 ms. The target stimulus was a 0.4 x 0.4-deg filled square presented at the center of one of the empty squares immediately after the offset of the prime stimulus. The inhibitory effect was replaced by a facilitatory effect when a dim prime stimulus was used instead of the bright one. Tassinari et al. (19) noticed in a first experiment an inhibitory effect of 41 and 39 ms when the target followed the prime stimulus by 65 and 130 ms, respectively. In this experiment the prime stimulus was an increase in luminance of the outline of one of four 1.2 x 1.2-deg empty squares centered on the horizontal meridian and the target stimulus was a 0.5 x 0.5-deg filled square appearing at the center of one of these empty squares; both stimuli lasted only 16 ms. In a third and fourth experiment of the study the inhibitory effect was 24 and 12 ms, respectively, at 130 ms stimulus onset asynchrony. At 65 ms stimulus onset asynchrony no effect of the prime

Table 1. Reaction time in milliseconds for each experimental condition of Experiments 1 and 2.

	Session 1/1,3				Session 2/2,4							
	S(1)	S(2)	GNG(1)	GNG(2)	S(1)		S(2)		GNG(1)		GNG(2)	
					Same	Differ	Same	Differ	Same	Differ	Same	Differ
Exp. 1	282 ± 10	295 ± 15	377 ± 22	403 ± 18	342 ± 19	306 ± 14+	329 ± 8	324 ± 20	347 ± 14	369 ± 15**	362 ± 18	364 ± 19
Exp. 2	261 ± 10	285 ± 14	414 ± 12	361 ± 15	323 ± 7	300 ± 9*	343 ± 15	341 ± 24	369 ± 15	420 ± 17+	327 ± 9	345 ± 10

Sessions 1 and 2 refer to Experiment 1 and sessions 1,3 and 2,4 refer to Experiment 2. S(1), S(2), GNG(1) and GNG(2), respectively, refer to simple task performed first, simple task performed second, go/no-go task performed first, and go/no-go task performed second. "Same" and "Differ", respectively, refer to the same position of the prime stimulus and target stimulus and to a different position of the prime stimulus and target stimulus. Data are reported as means ± SEM.
*P = 0.03, **P = 0.02, +P = 0.01, for "Same" *vs* "Differ" (Newman-Keuls test). Other statistical differences are indicated in the text.

stimulus was observed. In these experiments the empty squares (four in the third experiment and two in the fourth experiment) were 2.2 x 2.2 deg large. The prime stimulus was 130 ms long. The second experiment of the study is interesting because, in contrast to the other three, no inhibitory effect was observed. The only difference between the stimulatory conditions of this experiment and those of the first one was the duration of the prime stimulus, that now always outlasted the target by 284 ms. More recently, an inhibitory effect of the prime stimuli was observed in a go/no-go task by Efron and Yund (20). The participants were required to respond when a square pattern (1.3 x 1.3 deg large) characterized by alternating black and white vertically oriented stripes was presented among several similar patterns and were required not to respond when it was absent. This inhibitory effect appeared at a stimulus onset asynchrony of 50 ms and increased monotonically up to stimulus onset asynchronies of 100 to 167 ms and then decreased. It decreased monotonically with distance from the prime stimulus, disappearing at 6 deg far from it.

Lambert and Hockey (6), Tassinari et al. (19) and Efron and Yund (20) suggested a sensory mechanism, namely paracontrast (a case of forward masking), for the early inhibitory effect they observed. Efron and Yund (20) in particular presented evidence that their inhibitory effect could not be caused by other potential factors, such as a reduction of neural responsiveness after the initial activation by a light flash or an inhibition of return to an attended location.

Some electrophysiological findings support the idea that a prime stimulus could inhibit processing of a target stimulus at short latencies. Single neurons in the monkey superior colliculus (21) and primary visual cortex (22) exhibit a weaker response to a stimulus presented in their receptive field center when this stimulus is preceded by another stimulus there. In the case of the superior colliculus neurons even a stimulus occurring at a location distant from their receptive field was able to attenuate the response to a subsequent stimulus in the center of the receptive field. These inhibitory effects were observed with stimulus onset asynchronies of 700 to 500 ms and interstimulus intervals of 200 to 0 ms for the superior colliculus, and stimulus onset asynchronies of 400 to 200 ms and interstimulus intervals of also 200 to 0 ms for the primary visual cortex.

The paracontrast explanation could be thought to be inappropriate for the early inhibitory effect we observed in the present experiment. In a previous study we did not obtain any evidence that the empty ring forward masks the vertical line inside the ring. Responses to this stimulus presented at the fixation point in a go/no-go task were equally fast when the stimulus was presented alone and when it was preceded at the same location by the empty ring. In comparison, responses to a cross inside the ring were faster (18 ms) when this stimulus was presented alone than when it was preceded by the empty ring (23). As in this particular experimental situation the prime stimulus was supposed not to exert any spatial attentional influence, since attention was properly oriented all the time, any masking influence should have shown up as it did when the target stimulus was the cross inside the ring. It should be considered, however, that masking processes tend to increase with eccentricity (see 24,25). Paracontrast would be larger at the eccentricity used here. In this case it could well have affected the vertical line inside the ring processing.

Tassinari and Berlucchi (26) considered the inhibitory effect of the prime stimulus they observed in a simple task at a stimulus onset asynchrony of 200 ms as having a sensory basis. They were wary, however, to identify it as paracontrast in part because it spread to a whole hemifield. More recently, Maruff et al. (27) demonstrated that the inhibitory effect of the prime stimulus they observed in a simple task at a stimulus onset asynchrony of 150 ms was strongly dependent on the temporal parameters of the stimulatory situation. The effect appeared only when there was no overlap of the prime stimulus with the target stimulus (interstimulus interval of 100 ms) and the target stimulus was short (50 ms). The authors did not propose a mechanism for this inhibitory effect. Its properties are certainly compatible with the idea that it was due to forward masking. In the absence of the prime stimulus the attentional influence would decrease. The short duration of the target stimulus would reduce central processing of this stimulus. Both factors would favor the expression of a masking influence.

An alternate explanation instead of forward masking for the inhibitory effect we observed could be the adoption by the volunteers of a more strict criterion for responding in the same position condition than in the different position condition, as a consequence of the relatively large number of times the prime stimulus was not followed by the target stimulus. While the slower reaction times observed in the second testing session as compared to the first testing session support the idea that a criterion increase really occurred, the possibility of a differential increase between the two position conditions seems not very likely. The organism tends to use the same strategy for responding in all trials of a block. In addition, had this differential criterion increase occurred for the simple task, one would expect the same to occur for the go/no-go task since in this case the response should also be witheld after the prime stimulus on half of the trials. There is no evidence for that.

The early facilitatory effect of the prime stimulus observed here in the go/no-go task performed first confirms previous literature data (e.g., 13) and results from our own laboratory (10). Its magnitude (22 ms), although not large, is still in the range of the magnitudes seen in other experiments from our laboratory. As discussed above, it would be due to the attentional influence of the prime stimulus.

The difference between the effects of the prime stimulus in the simple task and the go/no-go task here could be due to the relative magnitudes of the attentional influence in the two cases, respectively weak and strong (depending on the specific attentional strategy adopted by the volunteers). A weak attentional influence in the simple task would allow the expression of an eventual masking influence of the prime stimulus. A strong attentional influence in the go/no-go task would overcome this opposite influence and express itself behaviorally.

Both the early inhibitory effect of the prime stimulus in the simple task and its early facilitatory effect in the go/no-go task disappeared when these tasks were performed second. To the best of our knowledge, these results are original in the literature. They are in accordance with the idea that different attentional strategies are adopted in the two tasks. The strategy normally used in the simple task, putatively of setting the gain of the automatic attention mechanisms to a low level, would interfere with the development of the strategy normally adopted in the go/no-go task, putatively of setting the gain of the automatic attention mechanisms to a high level, reducing the attentional influence of the prime stimulus in this task to about the level of its masking influence. In the same way, the strategy normally used in the go/no-go task would interfere with the development of the strategy normally adopted in the simple task, increasing the attentional influence of the prime stimulus in this task to about the level of its masking influence.

The hypothesis that different attentional strategies are used in simple and complex tasks could be questioned. It could be said that different ways of processing the prime stimulus in the two types of tasks could also lead to results as the ones we obtained. Automatic attention influence could still be higher in complex tasks than in simple tasks. This would occur, however, not because of a difference in the gain setting of its mechanisms, but because the prime stimulus would be processed in such a way in the former tasks that it would be able to activate more of these mechanisms than in the latter ones. We cannot rule out this alternative. We prefer the attentional strategy hypothesis, however, mainly because it seems more appropriate to explain the interference between the two kinds of tasks. A task-related sensory mechanism, presumably, should not be so much affected by previous experience with a different task.

Experiment 2

In the previous experiment we demonstrated that performing a go/no-go task leads to the disappearance of the early inhibitory effect of the prime stimulus in a subsequent simple task and, similarly, performing a simple task leads to the disappearance of the early facilitatory effect of the prime stimulus in a subsequent go/no-go task. This abolition of the early effects of the prime stimulus was explained by an interference of the attentional strategy putatively used by the volunteers in one type of task with the development of the attentional strategy putatively used by them in the other type of task.

The simple and the go/no-go tasks were performed in the same testing session in that experiment. It would be interesting to determine whether the putative attentional strategies developed in these tasks may be long-lasting. This could give an idea about whether they involve just temporary neural activity changes or more permanent, possibly structural, neural changes. The present experiment investigated whether the suppression of the early effects of the prime stimulus caused by previous testing would still occur with the two tasks performed one or more days apart.

Method

Participants. Six male and six female volunteers with the characteristics described in Experiment 1 participated in the experiment.

Procedure. Each volunteer participated in four testing sessions on separate days (not more than seven days apart). These sessions consisted of two blocks, each with 64 trials.

In the first and the third testing sessions only the S2 or the S2+/S2- were presented. In the second and the fourth testing sessions the S1 was added. Half of the participants performed the simple task in the first and second sessions and the go/no-go task in the third and fourth sessions. The other half of the participants performed the go/no-go task in the first and second sessions and the simple task in the third and fourth sessions. All other experimental conditions were exactly as in Experiment 1.

Data analysis

The participants were divided into a group that performed the simple task first (group S-G) and a group that performed the go/no-go task first (group G-S). Each participant's reaction time and accuracy for each condition were calculated as in Experiment 1.

Reaction time data for the first and third testing sessions and those for the second and fourth testing sessions were treated separately. The first set of data was submitted to a repeated measures ANOVA having as factors the group and the task. The second set of data was equally submitted to a repeated measures ANOVA having now as factors the group, the task and the S1-S2/S2+ relative position. An additional repeated measures ANOVA was applied to the data of the second and fourth sessions of each group. Factors in these ANOVAs were task and S1-S2/S2+ relative position. In every case, when appropriate, the data were further analyzed by the Newman-Keuls test.

Accuracy data were analyzed exactly as in Experiment 1.

Results and Discussion

The mean/median time interval between the second and fourth testing sessions was 3.9/3.5 days.

For the first and third testing sessions there was no interaction between group and task ($F_{1,10}$ = 1.57, P = 0.2). There was a main effect of group ($F_{1,10}$ = 7.25, P = 0.02) and of task ($F_{1,10}$ = 97.98, P<0.001). Group S-G had a shorter reaction time than group G-S. Reaction time in the simple task was longer when the task was performed second than when it was performed first. On the contrary, reaction time in the go/no-go task was shorter when the task was performed second than when it was performed first. As expected, reaction time was shorter for the simple task as compared to the go/no-go task (Table 1).

It is apparent that performing any one of the two tasks in this experiment influenced the later performance of the other one in the absence of the prime stimulus. The directions of the observed changes are compatible with the idea that in the simple task the participants adopted a strategy that would favor faster responses while in the go/no-go task they adopted a strategy that would favor slower responses. These strategies would be kept for at least one day. The appearance of task-related strategies in the absence of the prime stimulus here but not in the previous experiment might be due to the different amount of experience of the participants with the first performed task. In the present experiment it was more extensive than in Experiment 1.

For the second and fourth sessions there was no main effect of relative position of the stimuli ($F_{1,10}$ = 2.20, P = 0.2), and no interaction between group and task ($F_{1,10}$ = 2.92, P = 0.1), between group and relative position of the stimuli ($F_{1,10}$ = 3.27, P = 0.1) or between group, task and relative position of the stimuli ($F_{1,10}$ = 0.37, P = 0.6). There was a main effect of group ($F_{1,10}$ = 7.67, P = 0.02) and of task ($F_{1,10}$ = 22.48, P<0.001), as well as an interaction between task and relative position of the stimuli ($F_{1,10}$ = 20.54, P = 0.001). Again, group S-G had a shorter reaction time than group G-S. Reaction time in the simple task was longer when this task was performed second than when it was performed first; reaction time in the go/no-go task was shorter when this task was performed second than when it was performed first. In the simple task, as expected, reaction time was shorter than in the go/no-go task. For the go/no-go task, reaction time was shorter when the S2+ occurred at the same position as the S1 than when it occurred at a different position (P = 0.001) (Table 1).

The independent ANOVA for group S-G did not show any main effect of task ($F_{1,5}$ = 4.02, P = 0.1) or of relative position of the stimuli ($F_{1,5}$ = 0.17, P = 0.7). The analysis showed an interaction between task and relative position of the stimuli ($F_{1,5}$ = 14.18, P = 0.01). Reaction time was longer for the same position condition than for the different position condition (P = 0.03) for the simple task (Table 1).

The independent ANOVA for group G-S did not show any main effect of relative position of the stimuli ($F_{1,5}$ = 3.19, P = 0.1) but showed a main effect of task ($F_{1,5}$ = 24.29, P = 0.004) and an interaction between task and relative position of the stimuli ($F_{1,5}$ = 9.06, P = 0.03). Reaction time was shorter for the same position condition than for the different position condition (P = 0.01) for the go/no-go task (Table 1).

In the second and fourth testing sessions the percents of anticipation, commission and omission errors for the simple task were 0.8, 8.4 and 1.4%, respectively. For the go/no-go task the percents of anticipation, commission and omission errors were 0.4, 5.4 and 2.2%, respectively. No effect of the prime stimulus on accuracy was observed for either task, regardless of the order in which the tasks were performed.

The results obtained in the second and fourth testing sessions of the present experiment were very similar to those reported for the second testing session of the preceding experiment. This fact confers additional significance to all of these results. The disappearance of the early effects of the prime stimulus in the task performed second in the present experiment demonstrates that the putative attentional strategy adopted in a first performed task is relatively stable with time and should involve structural neural changes. This observation is important and indicates that researchers should not use experienced volunteers, especially ones previously tested in tasks different from the one currently being used. Special care should be taken with staff members and graduate students since, in view of their easy availability, they may have already been exposed to other reaction time tasks in other attention studies.

Experiment 3

One could question whether the disappearance of the early effects of the prime stimulus observed in the two previous experiments may have been caused by a habituatory process suppressing the central actions of this stimulus, rather than by a competition between a previously used attentional strategy and the attentional strategy normally employed in the second task. This possibility is suggested by some findings of Lupiáñez et al. (12) who demonstrated a decrease of the early facilitatory effect of the prime stimulus in both a simple task and a choice task across eight blocks of trials (800 repetitions of the stimulus).

In a previous study we did not observe any reduction of the early facilitatory effect of the prime stimulus in a go/no-go task across eight blocks of trials (512 repetitions of the stimulus) (10). As the volunteers in Experiments 1 and 2 of the present study were exposed to only 128 repetitions of the prime stimulus in the first task, they should not have had enough exposure to this stimulus to habituate to it. Anyway, we decided to check this alternate explanation for the results obtained with the second performed task in these experiments.

We determined whether the early inhibitory effect of the prime stimulus in the simple task would disappear if the volunteers were submitted to additional probing sessions with this same task. If it did, then the disappearance of the early facilitatory effect of the prime stimulus in the go/no-go task performed second in our Experiments 1 and 2 should be explained more parsimoniously by a previous habituation of the volunteers to this stimulus.

Methods

Participants. Six male and six female volunteers with the characteristics described in Experiment 1 participated in the experiment.

Procedure. Each volunteer participated in four testing sessions on separate days (not more than seven days apart). These sessions consisted of two blocks, each with 64 trials.

In the first testing session only the S2 was presented. In the other three testing sessions there was also the S1. All other experimental conditions were exactly as in Experiment 1 for the simple task.

Data analysis

Reaction time and accuracy data for each participant were calculated as in Experiment 1.

Reaction time data corresponding to the second, third and fourth testing sessions were submitted to a repeated measures ANOVA, having as factors the session and the S1-S2 relative position. When appropriate, these data were further analyzed by the Newman-Keuls test.

Accuracy data (number of slow responses) corresponding to the two relative positions of the S1 and the S2 and to the second, third and fourth testing sessions were submitted to a Friedman ANOVA. When appropriate, the same position and the different position data of each session were further compared by the Wilcoxon test. Adopted significance levels were 0.05 for the Friedman ANOVA and 0.01 for the Wilcoxon test.

Results and Discussion

The mean/median time interval between the second and the fourth testing sessions was 2.2/2.0 days.

There was a main effect of session ($F_{2,22}$ = 5.07, P = 0.02) and a main effect of S1-S2 relative position ($F_{1,11}$ = 23.13, P = 0.001). Session by S1-S2 relative position interaction was not significant ($F_{2,22}$ = 0.36, P = 0.7). Reaction times were shorter in the third and fourth testing sessions than in the second one (P = 0.02 and P = 0.02, respectively). Reaction time was longer in the same position condition than in the different position condition (Table 2).

The percents of anticipation, commission and omission errors were 0.9, 5.0 and 0.5%, respectively. No effect of the prime stimulus on accuracy was observed for the three sessions.

The early inhibitory effects of the prime stimulus observed in the second, third and fourth testing sessions were 13, 15 and 17 ms, respectively. The absence of any interaction between the session and the S1-S2 relative position factors indicates that the magnitude of the early inhibitory effect of the prime stimulus did not significantly change across the testing sessions. There was thus no long-term habituation of the volunteers to this stimulus.

The results of the present experiment indicate that a habituatory process was most likely not responsible for the disappearance of the early facilitatory effect of the prime stimulus in the go/no-go task performed second in our first two experiments.

Experiment 4

In this experiment we determined whether the early facilitatory effect of the prime stimulus in the go/no-go task would disappear in case the volunteers were submitted to additional probing sessions with this same task. If it did, then the disappearance of the early inhibitory effect of the prime stimulus in the simple task performed second in Experiments 1 and 2 should be explained more parsimoniously by a previous habituation of the volunteers to this stimulus.

Methods

Participants. Six male and six female volunteers with the characteristics described

Table 2. Reaction time in milliseconds for each experimental condition of Experiments 3 (simple task) and 4 (go/no-go task).

	Session 2		Session 3		Session 4	
	Same	Differ	Same	Differ	Same	Differ
Exp. 3	340 ± 9	327 ± 10	328 ± 8	313 ± 8	326 ± 11	309 ± 11**
Exp. 4	341 ± 10	356 ± 9	328 ± 7	344 ± 8	316 ± 8	339 ± 9*

"Same" and "Differ", respectively, refer to the same position of the prime stimulus and target stimulus and to a different position of the prime stimulus and target stimulus. Data are reported as means ± SEM.
*P = 0.003, **P = 0.001, for "Same" *vs* "Differ" (Newman-Keuls test). Other statistical differences are indicated in the text.

in Experiment 1 participated in the experiment.

Procedure. Each volunteer participated in four testing sessions on separate days (not more than seven days apart). These sessions consisted of two blocks, each with 64 trials.

In the first testing session only the S2 was presented. In the other three testing sessions there was also the S1. All other experimental conditions were exactly as in Experiment 1 for the go/no-go task.

Data analysis

Reaction time and accuracy data for each participant were calculated as in Experiment 1 for the go/no-go task.

Reaction time and accuracy data were analyzed exactly as in Experiment 3.

Results and Discussion

The mean/median time interval between the second and fourth testing sessions was 3.8/4.0 days.

There was a main effect of session ($F_{2,22}$ = 8.14, P = 0.002) and a main effect of relative position of S1 and S2+ ($F_{1,11}$ = 14.08, P = 0.003). Session by S1-S2 relative position interaction was not significant ($F_{2,22}$ = 1.41, P = 0.3). Reaction times were shorter in the third and in the fourth testing sessions than in the second one (P = 0.03 and P = 0.002, respectively). In the same position condition, reaction time was shorter than in the different position condition (Table 2).

The percents of anticipation, commission and omission errors were 1.1, 7.3 and 1.2%, respectively. Accuracy was greater for the same position condition than for the different position condition in the second testing session (P = 0.01) and in the third testing session (P = 0.009) but not in the fourth testing session.

The early facilitatory effects of the prime stimulus observed in the second, third and fourth testing sessions were 15, 16 and 23 ms, respectively. Although relatively small, these effects were highly statistically significant. The absence of any interaction between the session and the relative position of S1 and S2+ factors indicates that the magnitude of the early facilitatory effect of the prime stimulus did not change significantly across the testing sessions. Clearly there was no long-term habituation of the volunteers to the prime stimulus. We did not consider the decreased accuracy of the early facilitatory effect of the prime stimulus since our experimental protocol was not designed to evaluate response accuracy but rather response latency.

The present finding extends previous results from our laboratory (10). The early facilitatory effect of the prime stimulus does not decrease significantly either when this stimulus is repeated many times in a single session or when it is repeated many times along three sessions separated by at least one day. As previously observed (10), although spatially noninformative, our prime stimulus was temporally informative. This could have caused it to acquire some significance for the volunteers and consequently to become more resistant to habituation. The possibility that some habituation could have developed with more testing sessions, however, cannot be excluded. In fact, according to the observations of Lupiáñez et al. (12), this should occur.

We can conclude from the present experiment that a habituatory process was also most likely not to be responsible for the disappearance of the early inhibitory effect of the prime stimulus in the simple task performed second in our first two experiments.

General Discussion

We demonstrated in the present study that a prime stimulus can exert very different net early influences in simple and go/no-go tasks. The same prime stimulus that leads to an early inhibitory effect in a simple task can cause an early facilitatory effect in a go/no-go task. The most parsimonious explanation for the early inhibitory effect observed in the simple task is that the weak attentional influence of the prime stimulus in this task is overcome by the masking influence this stimulus would also exert. In the case of the go/no-go task, the strong attentional influence of the prime stimulus in this task would easily overcome its masking influence, leading to the observed early facilitatory effect. The small early facilitatory effect observed by Posner and Cohen (2), Maylor and Hockey (3), Lambert and Hockey (6), Collie et al. (7), Lupiáñez et al. (11-13), and Pratt and McAuliffe (14) in simple tasks may be probably due to a very low or absent masking influence of the prime stimulus in their experimental conditions.

We propose that the weak attentional influence of the prime stimulus in the simple task may be due to the adjustment of the gain of the automatic attention mechanisms to a low level. In the same way, the strong attentional influence of the prime stimulus in the go/no-go task may be due to the adjustment of the gain of the automatic attention mechanisms to a high level. By gain level one should understand the basal activity of the neurons responsible for automatic attention. When mobilized by the prime stimulus, these neurons would facilitate processing of subsequent visual stimuli in the stimulated region of the space and inhibit processing of subsequent visual stimuli in distant regions of the space. It is not known where exactly these neurons are located and how they act to affect sensory processing. They might form topographically organized feedback loops (see 28) involving, among other areas, the superior colliculus and the inferior parietal cortex (see 27).

The reason for these particular attentional strategies being adopted in the simple task and the go/no-go task would be their specific demands. In simple tasks one has to recognize the occurrence of the target stimulus and always respond to it. In go/no-go tasks it is necessary to discriminate between the two target stimuli and respond or not according to the stimulus presented. Presumably target stimulus processing would be less elaborate in the former case and more elaborate in the latter, correspondingly requiring less and more mobilization of the attentional mechanisms. Evidence indicating that task demands can determine the attentional strategy employed by individuals does exist in the literature. For example, Folk et al. (16,17) demonstrated that invalid abrupt-onset precues produce early costs for targets characterized by an abrupt onset but not for targets characterized by a discontinuity in color, and, conversely, invalid color precues produce greater early costs for color targets than for abrupt-onset targets. Some results obtained by Lupiáñez et al. (13) are particularly interesting. These investigators observed that the early facilitatory effect of the prime stimulus in a choice task could last a shorter or longer time in the trials. They suggest this would depend on the balance between the need to differentiate the target stimulus from the prime stimulus and that to integrate the target stimulus across time.

The finding that previous testing with the prime stimulus in one of our tasks completely abolished its early effect in our other task represents a very strong indication that different attentional strategies were adopted by the volunteers in these tasks. It would be exactly the interaction between the formerly adopted strategy and the strategy normally adopted in the second performed task (plus the masking influence of the prime stimulus) that would lead to the disappearance of the early effects.

Automatic attention would differ between simple and complex tasks by its intensity. A somewhat different hypothesis was advocated by Lupiáñez et al. (13). These authors suggested that automatic attention would usually last a shorter time in a simple (detection) task than in a complex (discrimination) task. This would favor event differentiation in the simple task, preventing the integration of cue and target that would make trials where the target follows the prime stimulus difficult to distinguish from catch trials. In complex tasks, events could be integrated normally as this would not disturb much the visual pattern processing required for discrimination.

Although attractive, the hypothesis of Lupiáñez et al. (13) does not seem to account for all of their data. These authors observed in Experiment 1 of their work a smaller early facilitatory effect of the prime stimulus in the detection task than in the discrimination tasks. We do not see how only changes in automatic attention duration could explain this result and, of course, some other similar findings reviewed in our Introduction. The findings of Experiments 1 and 2 of the present study also cannot be satisfactorily explained by the hypothesis as it was stated. Perhaps attentional influence is both less intense and more brief in simple tasks than in complex tasks. The different gain levels of the automatic attention mechanisms in these two types of tasks, proposed here, could easily lead to that.

The late facilitatory effect caused by voluntary attention was also demonstrated to be smaller in simple tasks than in complex tasks (e.g., 29). No attempt has been made so far to explain this difference. We suggest that it is related at least partially to the specific ways the volunteers mobilize their voluntary attention mechanisms in these tasks, as a consequence of their specific demands. As for automatic attention, there is evidence that voluntary attention depends heavily on task demands (30).

It is remarkable that the putative specific attentional strategy of the first performed task was not simply completely replaced by the putative specific attentional strategy of the second performed task in our experiments. This suggests that adopted attentional strategies are not easily abandoned. It would be interesting to determine whether the putative specific attentional strategy of the task performed second is fully recovered in additional testing sessions using this task.

No change in the late facilitatory effect due to voluntary attention was reported by Bédard et al. (29) when testing their volunteers in a simple task before and after a choice task and in a choice task before and after a simple task. The putative specific ways of mobilizing voluntary attention mechanisms would thus be less stable than the putative specific ways of mobilizing automatic attention mechanisms. This is not a surprise considering the high degree of involvement of cognitive factors in voluntary attention generation.

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