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The effects of location cuing on redundant-target processing

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Abstract The present study is concerned with the *redundany gain*: the observation that subjects respond faster to simultaneously presented redundant targets than to single targets. This finding is usually interpreted as evidence for parallel, self-terminating, unlimited-capacity processing. Alternatively, it has been claimed that the reaction-time advantage with redundant targets is simply due to spatial uncertainty under single-target conditions. The present study tested this hypothesis. In Experiment 1, subjects responded when one, two, or three letters E were presented, and refrained from responding when one, two, or three letters F were presented. In half of the trials, location uncertainty was eliminated by presentation of a line segment at one of the locations of the subsequently appearing target letters. The results reject the alternative spatial-uncertainty explanation: even when the location of the impending target is cued in advance, there is no attenuation of the redundancy gain. Experiment 2 served as a control experiment and showed a clear redundancy gain, even in conditions in which it was ensured that, before display onset, attention was directed to a location of one of the impending targets.

Introduction

The present article is concerned with the extent to which items can be processed in parallel across the visual field. In order to test between parallel and serial-processing models, Van der Heijden and colleagues (Van der Heijden, 1975; Van der Heijden, La Heij, & Boer, 1983; Van der Heijden, Schreuder, Maris, & Neerincx, 1984) employed a so-called redundant-target detection task in which subjects respond to displays containing redundant targets (see also, e. g., Egeth, Folk, & Mullin, 1989; Mordkoff & Yantis, 1991). The general finding is that the time to identify the target decreases as the number of targets present in a display increases.

In the study of Van der Heijden et al. (1983) subjects had to respond when one, two, or three letters E were presented, and refrain from responding when one, two, or three letters F were presented. The results showed that subjects responded most slowly when only one E was presented, somewhat faster when two Es were presented, and most quickly when three Es were presented. This result is known as a *redundancy gain* or *redundant-target effect*. The results of Van der Heijden et al. (1983) are considered to be evidence for parallel, self-terminating, unlimited-capacity processing. It is assumed that each signal occurrence is separately and simultaneously processed. The signal that finishes processing first initiates the response. Because the processing of n letters occurs independently, in parallel, and without capacity limitations, the response time is determined by the fastest of n processes, indicating that the response latency decreases as the number of targets increases. Limited-capacity, self-terminating models that assume that only one target is processed at a time predict that response latency is invariant with the number of targets.

Van der Heijden et al.'s (1983) conclusions regarding parallel, unlimited-capacity processing have recently been challenged by Bundesen (1990). He argued that the redundancy gain was due to incomplete foreknowledge of the spatial locations of targets (see also Van der Heijden et al.'s 1983 discussion on the favored-position artifact). Bundesen (1990) suggests: "The proposed account of the redundancy gain like that of Van der Heijden et al. (1983) makes an interesting prediction: If position uncertainty is entirely eliminated, no redundancy gain should be found" (p. 533). In Bundesen's theory, if the location of an element is precued, subjects increase the attentional weight of the element in the cued location by increasing the "pertinence value" of the cued location. Increasing the attentional weight of the element facilitates selection of that element, that is, it speeds up the processing of the element at the expense of other elements. In the one-target condition, when there are

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three possible target locations, there is a two-thirds probability that a subject will select a location that does not contain a target, giving relatively long reaction times (RTs). When more targets are present, the probability that subjects will select a location that does not contain a target is reduced, and therefore faster mean RTs are to be expected. With three targets, there is a target on every location, giving the fastest reaction times. In line with Bundesen (1990), redundancy gain should disappear when spatial uncertainty is eliminated, suggesting that the RTs for the one-target, two-target, and three-target conditions would be exactly the same.

Bundesen's (1990) hypothesis is supported by letter-recognition studies in which subjects know that they have to respond to the center letter of a linear string of letters presented just above the fixation dot (e. g., Eriksen & Eriksen, 1979; Krueger & Shapiro, 1980). In these studies, the time taken to respond to single-letter displays was the same as the time taken to respond to multiple, redundant-target displays. Although these findings might be interpreted as evidence for Bundesen's claim that the redundancy gain is due to spatial uncertainty, it should be realized that an alternative explanation is possible. Because the target letter was presented in the center of the linear array, the redundant targets were always projected on to retinal positions with acuity reduced in relation to the target (see also Van der Heijden, 1992, p. 182). Because subjects knew the location of the target in advance, it was possible to make an eye movement toward the target location. Such eye movements should enhance differences in retinal acuity among elements presented in the center and at the periphery. Obviously, elements projected onto positions with a reduced retinal acuity do not have the same chance of winning the parallel-processing race as elements projected onto the fovea. This might be the reason that in these circumstances no redundancy gain is found. The present study does not contain these shortcomings. Because elements were presented in a circular display and directed eye movements were prevented, it was ensured that all elements were projected onto retinal positions that had the same retinal acuity.

In the present study, only one location of the one, two, or three impending target letters was cued in advance in order to eliminate target uncertainty. Two hypotheses can be tested. If the pattern of results such as the redundancy gain is due to spatial uncertainty, as was suggested by Bundesen (1990), cuing the location of one of the targets before display onset should reduce the redundancy gain in relation to a condition in which there is no advance cuing of the target location. Specifically, when there is a location cue, the RT for the one-target and two-target conditions is about the same as the RT for the three-target condition, in which there is no advance cuing (see also, Theeuwes, 1993, pp. 128–129).

Alternatively, if redundancy gain reflects the finishing time of a race among signals that are processed simultaneously (e. g., Van der Heijden et al., 1983), location cuing should not affect the size of the redundancy gain.

Experiment 1

Experiment 1 was modeled closely after the research of Van der Heijden (Van der Heijden et al., 1983). Subjects had to respond when one, two, or three letters E were presented, and refrain from responding when one, two, or three letters F were presented – a Go/No-Go procedure. The Go/No-Go procedure reduces response-competition effects (e. g., Van der Heijden et al., 1984). On half of the trials, 66 ms before display onset, a small line segment was presented at the center of one of the locations containing a target letter. This line segment served as a location cue in order to ensure that there was no spatial uncertainty as to the location of one of the impending targets. The line segment was presented at the same location of the middle horizontal line in the E and F letters. Previous research investigating the effect of location cues has demonstrated that a 50-ms cue-to-target SOA is sufficient to obtain reliable location-cuing effects (Eriksen & Hoffman, 1973; Murphy & Eriksen, 1987).

Method

Subjects. Eight right-handed subjects, ranging in age from 17 to 28 years, participated as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus. An SX-386 Personal Computer (G2) with an NEC Multisync 3D VGA color screen using the Micro Experimental Laboratory software package controlled the timing of the events, generated pictures, and recorded reaction times. The space-bar of the keyboard was used as a response button. The stimuli were presented in white (21.0 cd/m^2) on a dark-gray background (0.5 cd/m^2). Each subject was tested in a sound-attenuated, dimly lit room, his or her forehead resting against a bar. The CRT was located at eye level, 54 cm from the bar.

Stimuli. The stimulus field consisted of one, two, or three roman capital Fs or one, two, or three roman capital Es, positioned at 1, 5, and 9 hours on a imaginary circle around the fixation point. The letters subtended approximately 0.40 ° × 0.21 ° in visual angle and the centers of the letters were located approximately 0.69 ° from the fixation point.

Procedure. The sequence of events was as follows. Initially, for 1,700 ms a white plus (+) sign was presented at the center of the CRT; 800 ms prior to display onset, the plus (+) sign was changed to an asterix in order to warn the subject. On half of the trials, 66 ms before display onset a small line segment (the ASCII character "–", approximately 0.30 ° in length) was presented at the center of one of the locations containing a letter. The line segment remained on until the stimulus field was presented. This line segment served as a location cue and was presented at the same location as the middle horizontal line in the E and F letters. Each location was indicated equally often. The stimulus field was presented for 133 ms, giving a total time between the onset of the cue and the offset of the display of 199 ms, a time interval too short to make effective eye movements. The number of targets present in the visual field was randomized within blocks. On half of the trials Es were presented; on the other half Fs.

Subjects were instructed to press the space-bar as quickly as possible when the stimulus field consisted of Es, and to refrain from responding in case Fs were presented. Both speed and accuracy were emphasized. If no response occurred within 1,000 ms, the trial was considered a No-Go. A tone sounded for 200 ms following both miss and false-alarm errors. Subjects were not informed about the occurrence of a location cue.

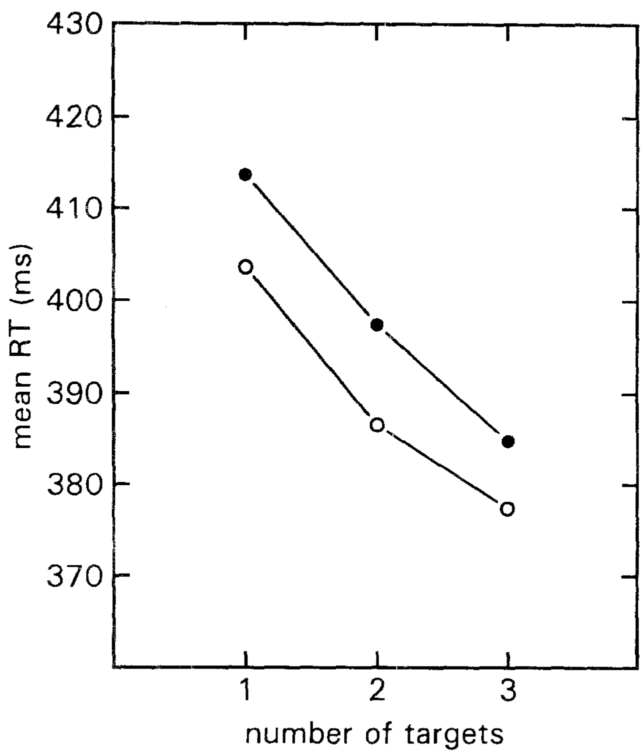

Fig. 1 Experiment 1: mean reaction time for E-present trials with (○) and without (●) a location cue

The practice session consisted of 72 trials. Each subject performed five blocks of 216 trials, each block lasting about 15 min. Between blocks of trials, there was a break of about 15 min. Each subject performed a total of 1,080 trials–that is, a total of 90 trials in each factor combination (Es vs. Fs; 1, 2, or 3 targets; location cue vs. no location cue).

Results

For E-present trials (Go trials), mean response times were calculated for each subject for both factor combinations (1, 2, or 3 targets; location cue present or absent). Mean correct RTs are shown in Figure 1.

Mean correct RTs were submitted to an ANOVA with number of targets and location cue present or absent as factors.

There was a main effect on RT for both number of targets, $F(2,14) = 40.5, p < .01$, and location cue, $F(1,7) = 10.8$, $p < .05$. As is evident in Figure 1, there is a clear redundancy gain: the time required to identify the target letter decreases as the number of target letters present in the display increases. The main effect of the location cue indicates that its presence simply speeds up this redundant-target processing. The absence of an interaction between number of targets and location cue ($F(2,14) < 1$), indicates that the redundancy gain is not affected by the advance cuing of a particular location.

Table 1 gives a summary of the error data. To achieve homogeneity of the error-rate variance, the mean error rates per cell were transformed by means of an arcsine transformation. This measure was submitted to an ANOVA with E present or F present, location cue present or absent, and number of targets as factors. None of the error effects was significant, which suggests that differences in response latencies are not due to trading speed for accuracy.

Table 1 Experiment 1: mean error rates (%) for E-present trials (misses) and F-present trials (false alarms) for number of targets (n) and location-cue condition

	Misses			False Alarms		
n	1	2	3	1	2	3
no location cue	0.3	0.7	0.4	0.8	1.8	1.2
location cue	0.8	0.5	0.4	1.7	1.4	2.5

Discussion

The absence of an interaction between the number of targets and the location cue indicates that the redundancy gain is not due to spatial uncertainty, as was suggested, for example, by Bundesen (1990). The finding that cuing does speed up RT without affecting the redundancy gain suggests a general alerting effect. This is important because it indicates that the cue was noticeable enough to affect processing.

Although it has been shown that this type of cue tends to attract attention to its location independently of its validity (e.g., Jonides, 1981; Theeuwes, 1991), one might still argue that the cue did not eliminate position uncertainty because subjects were capable of ignoring the tendency of the exogenous cue to attract attention.

Experiment 2

Experiment 2 was designed to rule out the possibility that subjects could ignore the cue. On each trial, one of the locations containing a target letter was cued either by a small line segment (identical to the one used in Experiment 1) or by a dot. Subjects were only allowed to respond to the display containing E(s) when the display was preceded by the small line segment. In case the E(s) were preceded by the dot, subjects had to refrain from responding. In cases F(s) were presented, subjects had to refrain from responding as well.

In line with most theories of visual attention (e. g., Müller & Humphreys, 1991; Van der Heijden, 1992), it is assumed that directing attention to a location is necessary in order to respond to the element presented at that location. In other words, in order to respond to the cue, subjects had to direct attention to the location of the cue. Since cue location was completely correlated with target location, it was ensured that before display onset, attention was directed to one of the target locations. If subjects responded accurately to the cue, it was guaranteed that there was no spatial uncertainty as to the location of the impending target.

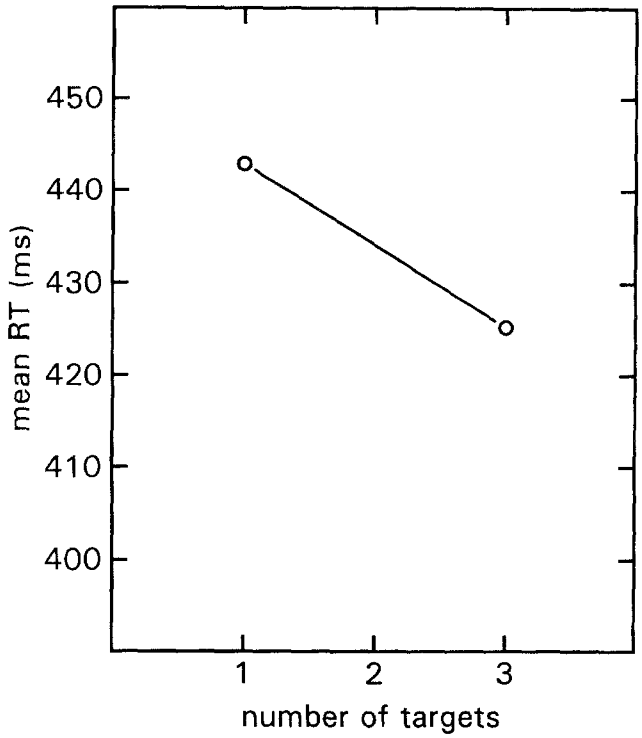

Fig. 2 Experiment 2: mean reaction time for E-present trials preceded by a cue to respond

Method

Subjects. Eight right-handed subjects, ranging in age from 16 to 24 years, participated as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus. The apparatus was identical to that in Experiment 1. The stimuli were white (10.0 cd/m^2) on a dark-gray background (0.5 cd/m^2).

Procedure. The task was identical to that in Experiment 1, except that subjects only had to respond to the stimulus field consisting of Es when, at the location of one of these Es, a small line segment was presented (identical to the one used in Experiment 1). When the Es were preceded by a small dot (the "." ASCII character), the subjects had to refrain from responding. In case of Fs preceded either by a "–" or a ".", they also had to refrain from responding. The cue (either the "–" or the ".") was presented for 83 ms, followed by the stimulus field, which was presented for 117 ms, giving a total time of 200 ms between the onset of the cue and the offset of the display, a time too short to make effective eye movements. Each of the three possible locations was cued equally often. One or three roman capital Fs or one or three roman capital Es were used, positioned at the same locations as those in Experiment 1. The "–" cue was displayed at the center of the letters corresponding to the middle horizontal line in the letter E or F. The "." cue was displayed at the base of the letters corresponding to the lower part of the vertical base in the letter E or F. Upon display presentation, the cues were no longer visible because the letters E and F covered them, precluding the occurrence of lateral masking.

The practice session consisted of 324 trials, followed by an experimental session of 324 trials. Subjects were provided with an opportunity for a break after every 81 trials, when they received feedback about their error scores on the preceding trials. Three types of error were recognized: failure to respond to Es preceded by a "–" (E misses), erroneous responding to Es preceded by a "." (E false alarms), and erroneous responding to Fs (F false alarms). In total, each subject received 108 E trials preceded by a "–" (E Go trials), 108 E trials preceded by a "." (E No-Go trials), and 108 F trials (F No-Go trials). On half of the trials there were three Es; on the other half one E. Half of the F trials were preceded by an "–", the other half by a ".".

Table 2 Experiment 2: mean error rates (%) for E-present trials with a cue to respond (E misses), E-present trials with a cue not to respond (E false alarms), and F-present trials (false alarms) for number of targets (*n*)

	E Misses		E False Alarms		F False Alarms	
n	1	3	1	3	1	3
	5.5	8.2	4.5	3.4	0.5	1.3

Results and discussion

Because one subject was not capable of discriminating between the "–" and the "." characters, no data were collected for this subject. For E Go trials, mean response times were calculated for each subject for the 1- and 3-target conditions. Mean correct RTs are shown in Figure 2.

There was a main effect on RT for the number of targets, $F(1,6) = 17.3, p < .01$. As is evident in Figure 2, even when subjects have to direct their attention to a specific location in order to perform the task accurately, a redundancy gain remains: the time required to identify the target letter is faster with three target letters than with one.

Table 2 gives a summary of the error data. The arcsine-transformed error data were submitted to an ANOVA with Type of Error (E misses; E false alarms; F false alarms) and Number of Targets as factors. None of the error effects was significant, suggesting that differences in response latencies were not due to trading speed for accuracy.

General discussion

The results of this study are clear. The absence of an interaction between the number of targets and the location cue, as observed in Experiment 1, indicates that the redundancy gain is not due to spatial uncertainty, as was suggested, for example, by Bundesen (1990). Experiment 2 shows that the redundancy gain remains, even when it is ensured that attention is directed to one of the target locations before display onset. In terms of Bundesen (1990), increasing the pertinence value of one particular location by advance cuing does not imply that stimuli from other nearby locations are not processed. In line with Van der Heijden et al. (1983; Van der Heijden, 1992) the results indicate that the redundancy gain is due to (fairly) unlimited-capacity, parallel, self-terminating processing.

The persistence of a redundancy gain in conditions in which attention is directed to a location in space suggests that directing focal attention to a target location does not exclude the processing of nearby identical elements. (similar effects are found in flanker experiments; e.g., Eriksen & Eriksen, 1974, 1979). Along similar lines, Fournier and Eriksen (1990) suggested a coactivation hypothesis that implies that "the simultaneous appearance of an identical form on a separate retinal area could have a synergistic effect that expedites the processing of the attended form" (p. 548). It is suggested that nonattended members of identical targets that do not gain access to focal attention, can still make a contribution to information processing at early perceptual levels.

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