The Effect of Semantic Relatedness and Typicality upon Visual Detection of a Target

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Abstract

In line with previous work by Treisman, many studies have demonstrated effects of perceptual discrimination between visual targets and distractors. Few studies however have investigated semantic discrimination effects. We report the findings of two experiments that were carried out in order to demonstrate the influence of semantic relatedness between a target word and distractor words in interaction with perceptual discrimination. The results demonstrate perceptual discrimination effects within a semantic task (e.g. from a group of words finding a word which means a type of fish), the role of degree of target typicality and, importantly, the effect of semantic relatedness between a target and its distractor context.

Introduction

Numerous studies have demonstrated the role of visual discrimination in target detection tasks. In particular, such studies have shown that target detection is simple, and unaffected by the number of distractors, when the target is completely distinguishable from its surrounding distractors (for example: identifying a blue X amongst greens Os and red Rs) (Treisman & Gelade, 1980). Conversely, if the target contains perceptual features that are common to the distractors (for example: identifying a red O amongst green Os and red Rs), then detection response time increases in direct proportion to the number of distractors (Treisman & Gelade, 1980; Treisman & Souther, 1985). This increase in response time depends specifically on the proportion of the first type of distractor (green Os) compared to the number of the second kind (red Rs). Target detection is facilitated when these two types of distractor do not appear in equal number in the visual display; as the numbers of each type approach equivalence, response time increases (Poisson & Wilkinson, 1992).

Whilst numerous studies have examined the effects of a target's and of its surrounding distractors' visual features, very few have investigated the influence of semantic features. In one study, White (1977) showed that semantic category could play a facilitative role in target detection; thus detecting the letter O is easier when surrounded by numbers rather than letters. In the same way, it is easier to detect the number O (zero) from a display of letters rather than other numbers. White's study was interesting because the semantic category was under the experimenter's control; in effect, the form of the target remained constant yet its meaning changed from the letter O to the number O. In other words, detection is made easier when the target belongs to a different semantic category to the distractors.

Such effects must operate for more complex stimuli such as words. The semantic properties of perceived words might influence target detection in situations such as scanning an index, a newspaper or a web page. Whenever a group of words is perceived, these words could be classified semantically (provided that

simultaneous and parallel semantic access is possible for each), allowing a semantically contrasting target to be distinguished with varying degrees of ease. In the present study, therefore, we hypothesized that a target typical of its semantic category (e.g. a trout as a type of fish) would be easier to detect from a visual display of a group of words than an atypical target (e.g. a shark as a type of fish). Furthermore, we hypothesized that it would be easier to detect a target that is distantly semantically related to its distractors (e.g. a fish amongst types of toy) than one which is more closely semantically related (e.g. a fish amongst types of insect). Although the semantic similarity facilitates the memory retrieval or the analogical transfer in problem solving (Gick & Holyoak, 1980), we hypothesize that it disturbes the visual search. Indeed, this semantic similarity could generate difficulty to determine if fixated item is the target or not. So it generates difficulty to reject this item because two words closely semantically related have more common properties than two words distantly semantically related (Poitrenaud, 1998). These common properties disturbe the great categorical attribution.

This study also examined the interaction of these semantic effects with visual effects by varying the number of distractors possessing the same forms (e.g. italic, bold …) and colors (e.g. black, red) as the target item, and in conditions where the target was composed of a conjunction of visual features (half red, half black amongst black and red distractors).

The first experiment in this study aimed to investigate the effects of target typicality, semantic relatedness, and the number of distractors that were visually identical to the target. The second experiment aimed to examine the effects of semantic relatedness and number of distractors in conditions where the target's perceptual features represented a conjunction of distractor perceptual features.

The effects of these independent variables were measured in terms of a number of dependent variables: success rate, response time and also eye movement variables (number of saccades, fixation duration). Effects of varying task stimuli semantically were measured using mean fixation times. This method enables processing difficulty due to task requirements or semantic material to be evaluated since items, which are more difficult to process involve longer fixation times (Just & Carpenter, 1980). For example, we hypothesized that trials where distractors had close semantic links to the target would produce higher mean fixation times than those where semantic links between distractors and target were weaker. Longer fixation times on trials where distractors have close semantic links to the target demonstrate the greater level of difficulty involved in deciding to reject a fixated item as not being the target item.

General Method

Participants

Participants were aged between 18 and 40 years old, were native French speakers and were capable of reading a monitor from a viewing distance of 0.50 m without the need for spectacles or contact lenses. Each participant was paid expenses of 30 euros.

Apparatus

The oculometer used to measure eye movements was a device using corneal reflection centered on the pupil (ASL 504 model). This technique involves illuminating the participant's eye using infrared light and collecting reflections from the cornea and pupil. The position of the eye in x and y coordinates is sampled every 20ms. Ocular fixation is defined using a minimum of five sampled points separated from each other by at least 0.5° visual angle. This apparatus also enables measurements to be taken of response time for each trial, number of fixations, average fixation time and saccadic amplitudes.

Trial presentations were generated and response time was measured using a microcomputer. Experimental stimuli were presented on a 21-inch flat monitor screen (resolution: 1280 x 1024 pixels; color: 32 bytes).

Stimuli

Each trial consisted of presenting 32 words (arial font, 16 pts) including the target on a white background. The position of the target was randomized, but counterbalanced across different areas designated by the columns and rows of the visual display. In order to study the effect of semantic relatedness, we created a database. This semantic database comprised 24 category classes: birds, insects, vegetables, fruits, toys, musical instruments, animals, vehicles, furniture, tools, male first names, female first names, famous authors, buildings, sweet foods, drinks, flowers, trees, weapons, professions, sports, items that are read, clothes; these were collected from 70 voluntary participants. Each participant was required to provide a list of as many words as possible for each of the 24 categories. The following types of word were excluded from the database: words containing less than 4 letters, compound forms (e.g. fruit juice) and words capable of belonging to two different categories (for example, in French, the word 'grenade' can signify both a weapon and a type of fruit). A minimum of 32 words was obtained for each category.

Procedure

Each participant was seated comfortably at a viewing distance of 0.50m from the monitor screen and the eye tracker video, with her/his chin stabilized in a chin rest. The experimenter read out the instructions which informed the participant that her/his eye movements

would be recorded and that s/he should avoid any further head movements. The instructions also described the experimental task to be carried out: 'the type of item to be detected will appear in the center of the screen, for example 'animal'; when you left-click on the mouse, a group of words will appear on the screen; your task is to find a word which fits, for example 'cat', as quickly as possible and without making errors; as soon as you have found it, press the key and say aloud which word you have found; if you cannot find it, say 'no' '. Next the experimenter began calibrating the oculometer; this process used a calibration card composed of nine colored dots on a white background. After calibration was complete, six practice trials were presented to the participant before the experimental trials began.

On each trial, the participant clicked on the mouse and the category of word to be detected was displayed at the center of the screen. When the participant clicked again, the 32 words appeared on the screen. As soon as the participant had detected the target, s/he clicked again and said aloud the detected word. The experimenter then recorded this word. If the participant could not detect the target, s/he clicked and then said 'no'.

The order of presentation of different trials for each of the different experimental conditions was randomized. When all trials were over, the experimenter obtained the ocular data for each trial. Each block of data included response time (as determined by the participant's click), the number of fixation points, average fixation time, and saccadic amplitude.

Data Analysis

Data were analyzed using an ANOVA statistical test with level of significance p=.05. Only those response times and eye movements (number of fixations, mean fixation duration) for trials where the target was detected correctly were included in the analysis. The mean fixation duration is the average time per fixation before target selection (total amount of fixation duration divided by the number of fixations).

Experiment 1

The aim of this experiment was to examine the effects of target typicality and target-distractor semantic relatedness on target detection. We hypothesized that target detection would be facilitated on trials with typical targets and distractors having only distant semantic links to targets. These effects were observed by varying the number of same color distractors (red or black) and by making targets both either red, black or half red and black (mixed color).

Method

Participants : 20 participants were recruited.

Stimuli : The target for each trial was taken from one of the 24 categories. The typicality of targets was determined by its inclusion frequency during the construction of the database: those words which were mentioned most often were designated 'typical' (more than ten times on 30 participants), whilst those mentioned least often were designated 'atypical' (less three times on 30 participants). For each target, distractors were either taken from a close semantic category (i.e. capable of being included together with words from the target's category in a single direct superordinate category; e.g. 'trout' from the 'fish' category together with words from the 'insects' category), or from a semantically distant category (i.e. not able to be grouped with the target in a single superordinate category; e.g. 'trout' from the 'fish' category together with words from the 'tools' category). Each array of 32 words included a word in red and black ('mixed' color: the left-hand part of the word in one color and the other part in another). Variations in the number of black words and red words enabled five experimental conditions to be created: c1 (1 red word and 30 black words), c2 (7 red words and 24 black words), c3 (16 red words and 15 black words), c4 (24 red words and 7 black words) and c5 (30 red words and 1 black word). The target could be any one of the 32 words and appeared in either 'mixed' color, or as the only word in its color, or having the same color as 6, 15, 23 or 29 of its distractors.

The experimental materials comprised 60 arrays according to the following design: T2 x D2 x C5 x M3, where T2 represented the typicality of the target (typical, atypical), D2 the semantic relatedness of the target and its distractors (distant or close), C5 the number of words in one color (1, 7, 16, 24 or 20) and M3 represented the color of the target (red, black or mixed). Each of the 20 participants responded to 2 trials per array (i.e. 120 trials).

Results

Target typicality effect: The mean percentage of correct responses was 82% for trials including typical targets and 62% for those including 'not typical' targets (F(1,18)=78.96, p<.01). The mean correct response time was 4.7s for typical targets and 5.97s for atypical targets (F(1,16)=34.09, p<.01) and the number of fixations was 10,34 for typical targets and 12,19 for atypical targets (F(1,16)=24,09, p<.01). There was no target typicality effect on mean duration fixation (448ms for typical target and 441ms for atypical target, F(1,16)<1, ns). Detection of typical targets was found to be easier than detection of atypical targets.

Semantic relatedness effect: The mean percentage of correct responses was 81% for trials where distractors had close semantic relatedness with the target and 68% for trials with only distant relatedness ($F(1,18)=66.03$, $p<.01$). The mean correct response time was 4.64s for the distant semantic relatedness condition and 6.02s for the close semantic relatedness condition ($F(1,16)=46.37$, $p<.01$). The mean fixation time was 430 ms for distant semantic relatedness trials and 460 ms for close semantic relatedness trials ($F(1,16)=16.66$, $p<.01$). Detection was found to be faster when semantically distant distractors surrounded the target rather than semantically close distractors.

Interaction between typicality and semantic relatedness : There was no interaction effect of target typicality and semantic relatedness on response success rate ($F(1,18)=2,95$; $p=.1$, ns) and on mean fixation duration ($F(1,16)<1$, ns) . In contrast, significant interaction effects were found for response time ($F(1,16)=43.25$, $p<.01$) and number of fixations ($F(1,16)=21.28$, $p<.01$). That is, participants took significantly more time and more fixations to detect an atypical target surrounded by closely semantically related distractors (see fig. 1).
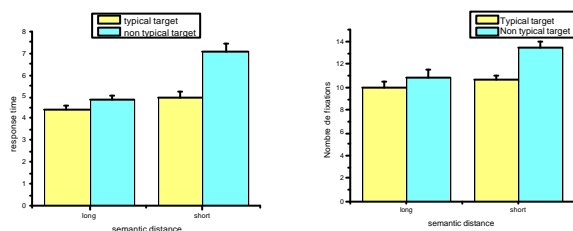

Figure 1: Response times and number of fixations as a function of semantic relatedness between targets and distractors and target typicality.

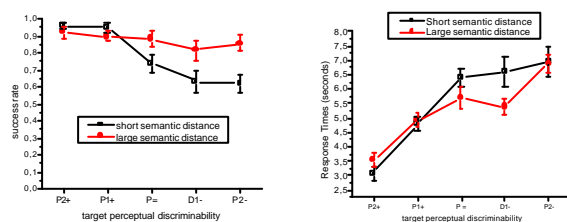**Effect of number of distractors that were identical to the target :**

Figure 2: Effect of number of distractors on success rate (%) and response time for non-conjunction targets (i.e. red or black).

When the target was either red or black (see fig. 2), increasing the number of distractors of the same color on trials (in fig. 2: P2+, P1+, P=, P1-, P2-, where P2+ corresponds to c1 for black target and c5 for red target,

and where P2- corresponds to c5 for black target and c1 for red target), where targets and distractors were closely related semantically caused success rates to fall from 81% to 50% ($F(4,72)=19.24$, $p<.01$) and response time to increase significantly from 3s to 7.5s ($F(4,68)=25.13$, $p<.01$). Detection of a target was influenced by the size of the perceptual group to which it belonged.
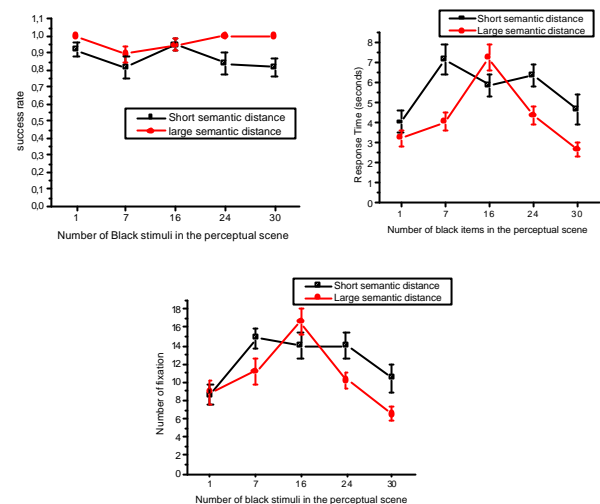

Figure 3: Effect of number of distractors on success rate (%), response time and number of fixations in trials with conjunction targets (i.e. red and black).

In contrast, when the target was a conjunction item (one part in one color, the rest in another), detection success rate was dependent on the ratio of red to black distractors (see fig. 3). That is, as the number of red distractors approached the number of black distractors, response time and number of fixations increased (test statistics for response time on trials with semantically close targets and distractors: $F(4,64)=4.78$, $p<.01$; for trials with semantically distant targets and distractors: $F(4,64)=22.32$, $p<.01$; test statistics for number of fixations/close semantic relatedness: $F(4,64)=4.59$, $p<.01$; for distant semantic relatedness: $F(4,64)=14.03$, $p<.01$). These results are consistent with Poisson & Wilkinson's (1992) findings.

Experiment 2

Typicality, semantic relatedness and (for conjunction targets) distractor type ratio effects were observed in experiment 1. Thus, detecting a conjunction target surrounded by seven red distractors and 24 black distractors took 4s whilst detecting a red target among six red distractors and 24 black distractors took 5s. Combining visual features within a conjunction target only exerted a negative effect on its detection when the target was surrounded by an equal number of red and

black distractors. However, no effect of semantic facilitation in association with visual facilitation was observed. On the contrary, the results of experiment 1 demonstrate that target detection is dependent on the number of same color distractors and that semantic facilitation effects only occur when a large number of distractors have the same color as the target (as shown in fig. 2).

The aim of experiment 2 was to investigate the influence of semantic relatedness on detection of a target predetermined by its superordinate category, by demonstrating a semantic facilitation effect in association with a perceptual facilitation effect. The search task, which involved finding a target in groups of small perceptual stimuli, was made more demanding by including visually more complex stimuli; words could be black or red, underlined or not, and in italic font or not. These combinations enabled eight perceptual groups to be constructed instead of two in experiment 1 (black and red). Moreover, the size of each of these groups was varied from one to four to seven elements. The target could belong to any one of these three groups and was then either the only stimulus from its perceptual group, or had the same perceptual features as three or as seven of its distractors.

Method

Participants : 40 participants were recruited.

Stimuli : Two different distractor conditions were created: close semantic relatedness between target and distractors (e.g. finding an insect amongst types of birds) and distant semantic relatedness between target and distractors (e.g. finding an insect amongst types of toys).

The stimuli varied according to the following perceptual features: color (red or black), font (italics or not), and underlining (underlined or not). Combinations of these three features enabled eight distinct groups of conjunction word stimuli to be constructed. The size of each group varied from one to four to seven words with the same perceptual feature conjunctions. The target, which could belong to any of these three groups, was therefore perceptually distinct within the one word group (0-DISTR), surrounded by three perceptually identical distractors in the four word group (3-DISTR), or surrounded by six identical distractors in the seven word group (6-DISTR).

A D2 x G8 x S3 experimental design enabled each semantic relatedness condition (D2) for distractor context to be combined with all visual feature conditions: eight word groups (G8) varying according to the three sizes (S3). This design produced 48 different arrays, each repeated three times.

Results

Semantic relatedness effects : The detection success rate was 94% on trials where targets were not closely related semantically to the distractors surrounding them, whereas the rate was 89% for trials involving close semantic relatedness between targets and their distractors ($F(1,38)=13.34$, $p<.01$). Mean response times were 7.15s for the close semantic relatedness condition and 8.16s for distant semantic relatedness ($F(1,38)=9.19$, $p<.01$). Mean fixation times were 389 ms and 425 ms respectively ($F(1,38)=24.45$, $p<.01$).

Effect of number of distractors sharing perceptual features with the target : Varying the number of distractors with the same perceptual features as the target had differing effects according to the degree of semantic relatedness between the target and its distractors (see fig. 4).
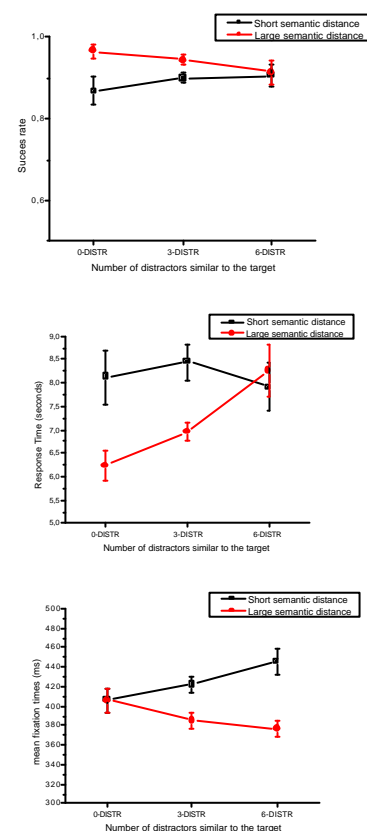

Figure 4: Success rate, response time and fixation time as a function of semantic relatedness between target and distractors and number of distractors identical to the target.

When the target was closely semantically related to the surrounding distractors, there was no observed effect on either success rate or response time. When the target was only distantly related semantically to its distractors (in conditions 0-DISTR and 3-DISTR),

detection success rates were higher (F(1,38)=16.33, p<.01) and response times were shorter (F(2,76)=4.71, p<.01) than in close semantic relatedness conditions. This was not true for the 7-DISTR condition (ns).

As shown in figure 4, increasing the number of distractors, which were perceptually identical to the target, in trials with distant semantic relatedness between targets and distractors, produced a significant increase in response time (F(2,76)=10.25, p<.01). This was not true for close target-distractor semantic relatedness conditions (F(2,76)=0.38, p=0.68; ns). In fact, the greater the number of distractors, the more the degree of semantic relatedness between target and distractors produced increases in mean fixation time (F(2,76)=10.55, p<.01).

Discussion and conclusion

The visual search for a word, which is an exemplar of a particular category, is facilitated by its perceptual features. For instance, the probability of detecting a single red word amongst a group of black words is high and search time is short. When the target is a conjunction of two perceptual features (colors), its detection is dependent on the ratio of red to black distractors. This effect, which was observed in both experiments, is similar to the 'pop out' phenomenon (Treisman & Gelade, 1980); until now, this phenomenon has been studied in terms of perceptual features and can be interpreted as an effect of discriminating a target from its surrounding distractors. We observed that the degree of a target's typicality affects its detection, in addition to the level of semantic relatedness between the target and its distractors.

This begs the question of how perceptual and semantic facilitation effects might interact. In experiment 1, when words were either red or black (two perceptual groups), we observed a semantic effect on trials where the target was the same color as a large proportion of its distractors. A type of 'semantic pop out' effect was observed because success rates and response times did not vary across trials with 7, 15 or 24 perceptually identical words and when targets and distractors were only distantly semantically related. However this result was not observed on trials where the target could be rapidly perceptually discriminated.

The stimuli used in experiment 2 were perceptually more complex (eight groups instead of two) and we observed a facilitation effect due to semantic relatedness when the target could be perceptually discriminated.

When perceiving a group of words, it is likely that we notice not only their perceptual features, but also their meanings very rapidly. If this is the case, it should be possible to investigate at a semantic level what Treisman & Gelade (1980) and Treisman & Souther

(1985) have observed at a perceptual level: the effect of the number of distractors in the visual array when distraction operates semantically. It should also be possible to study the effect of different variables on a conjunction target, which is a target that could belong to two different categories (e.g. in French, 'grenade' is both a type of fruit and a weapon). Our study represents a first step in that direction.

Our study completes work on visual search by integrating semantic features and do have some implications in several psychological domains. For example, the first experiment shows that perceptual discrimination of a target that is semantically close to the background, facilitates its detection. This perceptual discrimination effect is less efficient for a target that is semantically distant to its background. We also found that a semantically distant background facilitates the detection of a non typical target. Note that this effect works for discrimination based on simple perceptual features structure. Finally, this study provides some bases to study the facilitation of visual search and it might help evaluating web interfaces from the task of searching a target.

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