Effects of Orthographic and Semantic Distractors on Visual Search for Single Words

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Abstract

Two experiments of visual search for a word within a list were designed. The goal was to assess the effects of the presence in the list of words either visually similar or semantically related to the target word. In experiment 1 ("literal" task), the participants were shown the target word in advance. In experiment 2 ("semantic" task), the target word was defined by a semantic clue. In the "literal" task, orthographic distractors resembling the target word strongly impacted the search, but there was also an effect of semantic associates. In the "semantic" task, orthographic distractors still had a stronger impact than semantic associates. Hence, the visual appearance of words would be a strong determinant of the efficiency of information search within documents even when what is searched for is not known precisely.

Keywords: visual search; eye movement recordings; semantic associates; orthographic similarity; words lists.

Introduction

Visual search for words within documents to get information is a task that most people perform daily, for instance when they browse a reference list in search of an article or when they search for a particular hyperlink on a Web page. These search tasks are complex, finalized activities, which are not easily mastered even by adults (Rouet, 2006). While the cognitive processes involved in reading have been well investigated using eye movement recordings (Rayner, Pollatsek, & Reichle, 2003), the mechanisms of visual search for verbal information are much less known.

Visual search for non lexical material (geometrical shapes, isolated digits or letters) is a strong research field in cognitive psychology. The typical experiment begins with presentation of a visual object that must be memorized. Then, the participant must search for this target item among more or less similar objects called "distractors". Several models of visual search for non lexical material have been designed (Wolfe, 2000).

This paradigm has only rarely been applied to visual search for single words within lists or arrays of more or less similar words or verbal expressions. A series of such studies was undertaken in the 1950's and 1960's (Neisser & Keller, 1965), but were more focused on the cognitive processes of word identification and learning than on the visual search processes themselves. Very few authors have studied visual search for words using eye movement recordings (Katayama & Yagi, 1992; Léger, Tijus, & Baccino, 2006; Ojanpää, Näsänen, & Kojo, 2002). However, to understand how people perform simple search tasks within controlled verbal material is a prerequisite to tackle more complex tasks like information search within Web sites or forms.

Visual search for single words was mostly studied using target words that were explicitly shown to the participants before the search phase ("literal" condition). In that case, the visual similarity of the target with surrounding words, the characteristics of the writing, the way the words are lined or arrayed within the search display strongly impact the efficiency of the search (Léger et al., 2006; Ojanpää et al., 2002). Bruce (1981) demonstrated that the time to find the target word increased with its similarity to the surrounding distractor words. However, the determinants and strength of these effects were not precisely investigated.

More recently, some authors have modified the task by asking participants to find target words that were not known in advance, but defined by a semantic clue (Léger, Tijus, & Baccino, 2005) like the super-ordinate category to which they belonged ("categorical" condition). In that situation, semantic factors like the level of semantic association between the target word and distractor words should have a stronger impact, since the meaning of distractor words must be assessed to check whether or not they correspond to the target. Such effects were indeed observed during rapid serial

visual presentation paradigms (Barnard, Scott, Taylor, May, & Knightley, 2004), but the extent to which the impact of the visual characteristics of the material is reduced compared to the condition where the target word is given must still be investigated.

When the target word is visually presented, the chronometric data of Harris, Pashler, & Coburn (2004) suggested that the distractor words were not semantically processed because their meaning did not influence search efficiency. However, the distractor and target words were not semantically related in these experiments. Rayner & Raney (1996) compared eye movements during reading versus searching for words. During reading, the duration of eye fixations on words depends on their frequency in the language, with rarest or ambiguous words fixated longer than common ones. In contrast, word frequency has no effect on fixation duration during visual search for a word within a paragraph. This also suggests that semantic processing of the non-target words is minimal. But other authors have argued for the existence of semantic priming effects of distractor words presented concomitantly to a priming task (Ariga & Kawahara, 2004; Mari-Beffa, Fuentes, Catena, & Houghton, 2000), which they consider evidence of automatic semantic processing of the distractor words. In addition, Henderson & Chard (1978) observed that searching for a word was faster when the target word and distractors belonged to different semantic categories.

This study presents two experiments, which were designed to get a better picture of the impact of visually or semantically related distractor words on visual search for single words within lists. The goal of these experiments was to assess how the presence in the list of words that were either visually similar to the target word ("orthographic" distractors sharing their first and last letters with the target words) or semantic associates of the target word ("semantic" distractors) impacted the search process. Eye movement recordings were used together with measures of search times and error rates to assess whether the eventual distracting effects resulted from an increase in the number and/or the duration of eye fixation on the orthographic or semantic distractors.

The two experiments involved the same participants and used the same experimental material, but differed by the nature of the search task. The idea was to check whether the impact of orthographic and semantic distractors on visual search for words depended on the nature of the task performed by the participants. **In experiment 1,** the participants had to perform a "literal" search task, in the sense that the target word was directly shown to them before the search phase. The participants knew the target word in advance. **In experiment 2,** the participants did not know in advance the target word they had to find. The target word was defined by a semantic clue, namely the super-ordinate category to which it belonged. Hence, the participants had to perform a "semantic" search task.

For experiment 1, the literature suggests that the visual characteristics of the word display would be the main determinants of the search process, but that some semantic processing of the distractor words might also be involved. The first hypothesis was therefore that orthographic distractors should have the strongest impact on the search task and induce a large increase of the time taken to find the target word and/or the error rate. In addition, a smaller effect of semantic distractors could not be excluded.

For experiment 2, the main hypothesis was that changing the nature of the task performed by the participants should lead to strong modifications of the respective impact of orthographic and semantic distractors on the search process. Definition of the target word by a semantic clue was expected to induce a strong impact of semantic distractors, and to suppress or strongly decrease the impact of orthographic distractors.

Material and Methods

Participants

Data for the two experiments were obtained from 36 undergraduate psychology students of the University of Poitiers who participated for course credits. They were all native French speakers and had normal or corrected-to-normal vision.

Apparatus

Experiments were performed with a TOBII 1750 eye-tracker, which displayed the stimuli on a 17" monitor using a screen resolution of 768 x 1,024 pixels. The eye tracker was driven via a Fujitsu/Siemens laptop and provided gaze positions at a sampling frequency of 50 Hz, with a precision of 0.5° of visual angle. The words used as stimuli were written in lower case letters using 14 points size Verdana font. The screen was at a viewing distance of about 60 cm.

Experimental Material

The stimuli for the two experiments consisted of 3 sets of 24 experimental and 8 filler lists of French words, which were built around 32 target words that were each typical exemplars of a particular super-ordinate category. Examples of target words include "corbeau" (raven) as an exemplar of the super-ordinate category "oiseau" (bird), or "pétrolier" (tanker) as an exemplar of "bateau" (boat).

Each list included 13 words, namely one target word and 12 "distractor" words displayed in a single column. Successive words in the list were separated by a 1 cm space. All words had 2 or 3 syllables (M = 7.2 letters, SD = 1.4 letters) and a frequency superior to 1 per million in French according to the "Lexique" database (New, Pallier, Ferrand, & Matos, 2001; http://www.lexique.org).

For each of the target words, three distinct lists were built with the following characteristics:

- The first list ("orthographic list") included 6 orthographic distractors, i.e. 6 words that shared at least the first and two last letters with the target word, and 6 neutral distractors that were neither orthographically nor

semantically related to the target word. Examples of orthographic distractors for the target word "corbeau" (raven) were "chameau" (camel) and "cadeau" (present).

- The second list ("semantic list") included 6 neutral and 6 semantic distractors that were semantically associated with both the target word and its super-ordinate category. The semantic distractors were not other exemplars of the category. Examples of semantic distractors for the target word "corbeau" (raven) and its super-ordinate category "oiseau" (bird) were "forêt" (forest) and "plumage" (feathers). The levels of semantic association between the target word, its category and each of the 12 distractors were assessed by 70 volunteers who judged on a 10-points scale the semantic association between the different pairs of words (1: no semantic association, 10: very strong semantic association). Within each list, the average ratings of the semantic association between all neutral distractors and the target word or its super-ordinate category were either 1 or 2, whereas the average ratings for the semantic distractors were all between 5 and 10.
- The third type of list ("neutral list") included 12 neutral distractors that were different from the neutral distractors included in the orthographic and semantic lists built around the same target word.

Procedure

All participants were tested individually. Each trial began with the presentation of a cross centered on the left side of the screen, where the participant had to position the mouse cursor. When the participant was ready, s/he pressed the space bar of the keyboard and a word appeared at the top-left corner of the screen.

In experiment 1 ("literal" task), the word shown to the participant was the target word itself, for instance "corbeau" (raven). **In experiment 2 ("semantic" task),** the word shown to the participant was the super-ordinate category prompting her/him to search within the words list for the unique exemplar of this category, i.e. "oiseau" (bird) was given as a clue to find the target word "corbeau" (raven).

Once the participant had memorized the word, s/he pressed the space bar and the list to be searched appeared. When the participant had found the target word, s/he had to click on it using the mouse. To begin another trial, the participant pressed the space bar again. The participants were told that there was always only one valid target word, were instructed to click on it as soon as they had found it, but were also told that they should not make any error.

All participants participated in both experiments. Half of them began with experiment 1 where the target word was known in advance, the other half with experiment 2 where the target word was defined by its super-ordinate category. Each of the two experiments included 12 experimental and 12 filler trials that were presented in random order, and was preceded by a series of ten practice trials aimed at familiarizing the participant with the task.

Each participant was tested on only one third of the experimental lists. In each experiment, the 12 experimental trials presented to any given participant used 12 distinct target words that were each inserted into either an orthographic (4 trials), semantic (4 trials) or neutral (4 trials) list. The 12 target words used in experiment 1 were always different from those used in experiment 2. The position of the target word was randomized within the bottom half of the list (i.e. positions 7 to 13) for the experimental lists, and within the top half (positions 1 to 6) for the filler lists. The non-target words were then distributed randomly across the 12 other positions.

Eye Movements Recordings and Data Analysis

Eye movements were recorded during the whole procedure and analyzed using the TOBII eye-tracker software (ClearView 2.7.1). Eye fixations were defined as any period where gaze stayed for 60 ms or more within a 20 pixels (0.7 cm, about 0.7°) diameter area. A fixation was attributed to a word if it fell within the 1.5 x 6 cm box enclosing each word of the lists. When calculating fixation durations, successive fixations on the same word were collapsed.

All trials where errors where made, i.e. where the participant did not select the right target word were excluded from further analysis. Data analysis was then performed for each experiment using the type of list as a within-participants factor. Dependent variables were the time taken to perform the visual search and the error rate.

Eye movement data were used to refine the analysis and compute for each list the number and nature of the distractor words that were fixated during the task, as well as the mean duration of these fixations. Following logarithmic transformations of the data, two separate analyses were conducted.

- For the orthographic and semantic lists, t-tests were used to compare the number and mean duration of fixations made on neutral versus orthographic or semantic distractors, respectively.
- In addition, the number and duration of fixations made on neutral distractors were compared across the three types of lists. Since there were twice more neutral distractors in the neutral than in the orthographic or semantic lists (i.e. 12 instead of 6), the number of fixations was normalized with respect to the number of neutral distractors present in each type of list, namely the number of fixations made on the neutral distractors of neutral lists was divided by two.

Experiment 1 ("Literal" Task)

Results

Error Rates and Response Times When participants knew in advance the target word to search for, the error rate was very low. Only two errors of target selection were observed over the 432 experimental trials performed by the 36 participants, i.e. less than 0.5%. No further analysis was therefore conducted for this variable.

The times taken by the participants to find the target words within each type of list are presented in Table 1.

Table 1: Response times (in milliseconds) obtained on each type of list in experiment 1.

Type of list	Mean	SD
Neutral	2392	436
Semantic	2647	657
Orthographic	3031	640

Following logarithmic transformation of the data that ensured normality and variance homogeneity, an ANOVA demonstrated that the type of list within which the target word was presented had a significant effect on the response times ($F(2,70) = 27.99$, $MSe = .094$, $p < .001$). Newman-Keuls post-hoc tests showed that, in accordance with our hypotheses, participants took more time to find the target word when orthographic ($p < .001$) or semantic ($p < .01$) distractors were present than when the list only contained neutral distracters. The increase of the response time was larger with orthographic than with semantic distractors ($p < .001$).

Eye Movement Data When the target word was presented within semantic lists, there was no significant difference between the number or duration of fixations made on the 6 semantic distractors and the 6 neutral distractors ($t(35) = .81$ and .58, ns). Within orthographic lists in contrast, orthographic distractors were both fixated more often ($t(35) = 3.63$, $p < .001$) and for longer durations ($t(35) = 5.68$, $p < .001$) than neutral distractors (Table 2).

Table 2: Mean (SD) normalized number (top) and duration (bottom, in milliseconds) of fixations made on each type of distractors in experiment 1.

	Nature of distractors		
	Neutral	Semantic	Orthographic
Neutral lists	2.4 (0.7)		
Semantic lists	3.0 (1.2)	2.8 (1.1)	
Orthographic lists	3.0 (1.0)		3.7 (1.3)
Neutral lists	213 (57)		
Semantic lists	204 (54)	200 (73)	
Orthographic lists	187 (42)		233 (46)

ANOVAs revealed a significant effect of the type of list on both the number ($F(2,70) = 5.07$, $MSe = .07$, $p < .01$) and duration ($F(2,70) = 3.87$, $MSe = .32$, $p < .05$) of fixations made on neutral distractors. Post-hoc Newman-Keuls tests demonstrated that the number of fixations on neutral distractors was higher for both semantic ($p < .05$) and orthographic ($p < .05$) lists than for neutral lists (Table 2). In addition, neutral distractors were fixated for less time in orthographic ($p < .05$) than neutral lists.

Discussion

As expected, the presence of orthographic distractors had a strong impact on the search process when the target word was shown in advance to the participants. The presence of semantic associates of the target word within the list also impacted the search, in accordance with data obtained by Henderson & Chard (1978) with category membership, but to a lesser extent.

Eye movement recordings revealed that when orthographic distractors were present, they were fixated more often than the neutral distractors of the list. This suggests that parafoveal vision of distractors that resemble the target word was sufficient to draw the attention of the participants towards them. Orthographic distractors were also fixated for longer durations, which suggests that more time was needed to distinguish them from the target word than for neutral distractors. Interestingly, the neutral distractors of orthographic lists were themselves fixated more often, but for shorter durations than the neutral distracters of neutral lists. Hence, the presence of several orthographic distractors looking alike would lead to a more thorough exploration of the list in general, but to a faster judgment of dissimilarity for the words of the list that do not resemble the target.

The impact of semantic distractors on the search process was not explained by a difference in the number or duration of fixations made on them relative to the neutral distractors of the list. However, visual search within semantic lists was associated with an increase in the number of fixations made on the neutral distractors of the list compared to the neutral distractors of neutral lists. As with orthographic distractors, the presence of several semantic associates of the target word would induce a more thorough examination of all the words in the list.

Altogether, the data show that orthographic distractors looking like the target word have a strong impact on the search process, but also that automatic semantic processing of the distractor words may occur to a certain extent in this situation (Ariga & Kawahara, 2004).

Experiment 2 ("Semantic" Task)

Results

Error Rates and Response Times When participants were given the super-ordinate category of the target-word they had to search for, the error rate in the identification of the target reached an overall value of 6.5% (28 errors out of 432 trials). The error rate was 3.5% when the target word was presented within neutral lists, 2.8% when orthographic distractors were present and 13.2% when semantic distractors were present. In accordance with our hypotheses, a non-parametric Friedman ANOVA demonstrated that the type of list had a significant effect on the error rate (Chi^2 *ANOVA* $(N = 36, df = 2) = 12.33$, $p < .01$). Post-hoc sign tests revealed that the error rate was higher for semantic lists than for neutral ($p < .05$) and orthographic ($p < .01$) lists.

The times taken by the participants to find the target words within each type of list are presented in Table 3.

Table 3: Response times (in milliseconds) obtained on each type of list in experiment 2.

Type of list	Mean	SD
Neutral	5004	887
Semantic	5465	1477
Orthographic	5670	1497

Following logarithmic transformation of the data that ensured normality and variance homogeneity, an ANOVA demonstrated that the type of list within which the target word was presented had a significant effect on the response times ($F(2,70) = 3.71$, $MSe = .021$, $p < .05$). Newman-Keuls post-hoc tests showed that contrary to our hypotheses, participants took more time to find the target word when orthographic ($p < .05$) distractors were present than when only neutral distractors were included in the list. The presence of semantic distractors only induced a marginally significant increase of the response time ($p = .09$). No difference was found between semantic and orthographic lists.

Eye Movement Data When the target word was presented within semantic lists, there was no significant difference between the number or duration of fixations made on the 6 semantic and 6 neutral distractors ($t(35) = 1.25$ and .82, ns). Within orthographic lists, orthographic distractors were fixated for longer durations ($t(35) = 2.65$, $p < .05$), but not more often ($t(35) = .29$, ns) than neutral distractors (Table 4). To check whether this effect was present from the beginning of the search on, a separate analysis was done on the fixations that occurred before the first fixation on the target word. Orthographic distractors (M = 268 ms, SD = 81) were still fixated for longer durations than neutral distractors (M = 243 ms, SD = 62; $t(35) = 2.72$, $p < .05$).

Table 4: Mean (SD) normalized number (top) and duration (bottom, in milliseconds) of fixations made on each type of distractors in experiment 2.

	Nature of distractors		
	Neutral	Semantic	Orthographic
Neutral lists	5.2 (0.9)		
Semantic lists	5.3 (1.7)	5.6 (1.6)	
Orthographic lists	5.5 (1.3)		5.6 (1.2)
Neutral lists	246 (61)		
Semantic lists	255 (71)	264 (75)	
Orthographic lists	245 (60)		286 (75)

ANOVAs did not reveal any effect of the type of list on either the number (non-parametric Chi^2 *ANOVA* ($N = 36$, $df = 2$) = 3.62, ns) or duration ($F(2,70) < 1$, ns) of fixations made on neutral distracters (Table 4).

Discussion

Experiment 2 was aimed at checking whether and how changing the task assigned during the visual search would modify the respective impact of orthographic and semantic distractors on the search process. With one exception, the data did not support our hypothesis that the nature of the task, and not the structure of the lists per se, would be the main determinants of the search.

The error rate was the only variable that behaved in accordance with this idea. Indeed, the presence of semantic associates of the target word induced a higher proportion of errors than that of orthographic and/or neutral distractors. In sharp contrast, semantic distractors only had a marginal effect on the time taken to find the target word, and the eye movements recorded during the exploration of semantic lists were not different from those obtained for neutral lists. This marginal effect contrasts with the results reported by Léger et al. (2005) and Barnard et al. (2004), who found that semantic distracters strongly disturbed visual search for words and word identification. However, in Léger et al. (2005)'s study, the distractors surrounding the target word were all members of the same super-ordinate category, whereas in the present experiment only half of the words were semantically related to the target word. Barnard et al. (2004) used rapid serial visual presentation paradigms instead of visual search. In this experiment, the participants must decide which of the words in the list best corresponds to the categorical clue given to define the target word. The discrepancy between the error rate and response time data suggests that decision about the suitability of a distractor as the target word is independent from the time spent looking at this distractor and from eye movement data.

The strong effect of orthographic distractors on the search time observed in experiment 1 persisted. It was associated with an increase in the duration of fixations made on the orthographic distractors compared to neutral distractors of the same list. This effect was observed from the beginning of the search on, before the first fixation on the target word, which eliminates the possibility that orthographic distractors may have an effect only once the target word has been seen. Even when the target word to search for is not precisely known, orthographic distractors resembling each other and the target word would be evaluated with more attention than neutral distractors.

The experimental material used in both experiments was the same and whatever the task, the effects of orthographic and semantic distractors on the visual search time were quite similar. Hence, experiment 2 suggests that the respective impact of the orthographic and semantic distractors on the time taken to find a target word within a list depends more on the structure of the list per se than on the nature of the search task. In particular, the data may be interpreted as evidence that the presence of several words looking similar within a list will slow down the search for any word within this list.

General Discussion

Qualitative comparison between the results of the two experiments confirms that to find a single word within a list of 13 words takes about twice more time in the semantic than in the literal condition. The increase of the response time was associated with both an increase in the number of fixated words and in the average duration of fixations on the words (about 250 ms in the semantic condition versus 200 ms in the literal condition). This probably reflects the fact that when the word to find is defined by a semantic clue, a semantic treatment of all or most words in the list is needed.

Taken together, the data presented here indicate that whatever the task assigned to participants, the presence with the target word of distractor words sharing the same first and last letters provokes a strong increase of the time taken to find the target word. This is in accordance with the work of Grainger & Whitney (2004), who demonstrated the particular importance of the first and last letter of a word for its identification. Other visual characteristics of words could have similar effects, like their global shape as defined by Lété & Pynte (2003).

The fact that orthographic distractors had a strong impact on the time taken to find a target word that was not precisely known in advance was unexpected, but may be explained in different ways. First, the mere presence of several words looking similar within a list might slow down search for any word within this list. This hypothesis will be tested in a near future. Second, one cannot exclude that seeing the name of a super-ordinate category given as a clue to define the target word may induce an unconscious pre-activation of the most typical exemplars of this category. In general indeed, the target words we used were chosen as much as possible to be among the most popular representatives of their category.

Whatever the explanation, the results of experiment 2 suggest that the visual appearance of the words used in documents will be a strong determinant of the rapidity and success of information search within these documents even when what is searched for is not known with precision. The semantic characteristics of the verbal material appear to have a lower impact on the time taken to find the information, but might in contrast strongly impact the relevance of the information that is found.

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