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Looking for a word or for its meaning? The impact of induction tasks on adolescents' visual search for verbal material

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Abstract

An eye-tracking experiment was conducted to examine whether the pre-activation of different word-processing pathways by means of semantic versus perceptual induction tasks could modify the way adults and 11- to 15-year-old adolescents searched for single target words within displays of nine words. The presence within the search displays of words either looking like the target word or semantically related to the target word was manipulated. The quality of participants' lexical representations was evaluated through three word-identification and vocabulary tests. Performing a semantic induction task rather than a perceptual one on the target word before searching for it increased search times by 15% in all age groups, reflecting an increase in both the number and duration of gazes directed to non-target words. Moreover, performing the semantic induction task increased the impact of distractor words that were semantically related to the target word on search efficiency. Participants' search efficiency increased with age because of a progressive increase in the quality of adolescents' lexical representations, which allowed participants to more quickly reject the distractors on which they fixated. Indeed, lexical quality scores explained 43% of the variance in search times independently of participants' age. In the simple visual search task used in this study, fostering semantic word processing through the semantic induction task slowed down visual search. However, the literature suggests that semantic induction tasks could, in contrast, help people find information more easily in more complex verbal environments where the meaning of words must be accessed to find task-relevant information.

Keywords Reading · Adolescents · Visual search · Induction task · Word recognition

Introduction

A majority of European teenagers use the Internet daily (Smahel et al., 2020), and in the USA many of them report that they are "almost constantly" online (Pew Research Center, 2018). Popular uses include social networking, playing games, and searching for information of interest. Most, if not all, of these activities involve the selective scanning of words, sentences, or texts, which places a heavy burden on cognitive and language processes (Wylie et al., 2018). Prior research suggests that the ability to scan verbal displays in order to find relevant information for the ongoing task develops progressively during childhood and adolescence (Hirsh, 2000; Kaakinen et al., 2015; Potocki et al., 2017). In this context, the examination of adolescents' proficiency in visual search for single words amongst other words becomes important to explain the challenges they might face when using more complex digital environments. However, research on the foundational aspects of visual search for words or phrases is still uncommon (for examples and

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reviews, see Boettcher & Wolfe, 2015; Vibert et al., 2019; Zhou et al., 2017). In particular, very few studies have examined the development of visual search for target words amongst other words during adolescence (Seassau & Bucci, 2013; Vibert et al., 2019).

Data from previous studies that investigated how children select task-relevant websites from search engine result pages indicated that young adolescents were more sensitive to the visual features of words than to the meaning of the phrases that described the websites (Walraven et al., 2008; Zhang & Quintana, 2012). For instance, Rouet et al. (2011) found that sixth graders tended to select irrelevant phrases (e.g., the highest train in the world) in response to a search query (e.g., the highest mountains in the world) if the matching keywords were capitalized (e.g., the HIGHEST train in the WORLD). However, when sixth graders read a short text about the search topic before performing the search, they were better able to select the semantically relevant menu entries (Rouet et al., 2011). Hence, fostering semantic processing by asking adolescents to perform a semantic task before searching for verbal information may help them more successfully find relevant information within texts or webpages.

The main goal of the present work was to examine whether the pre-activation of different word-processing pathways, by means of either a semantic or a perceptual induction task that participants performed before the visual search phase, could influence the way adolescents and adults scan simple verbal displays when searching for a target word. The theory of attentional sensitization of unconscious cognition (Kiefer & Martens, 2010) was used as a framework to compare the impact of semantic versus perceptual induction tasks on visual search efficiency. This simple experiment, in which participants searched for one word within a display of nine words that were distributed across the screen, was viewed as an essential step towards understanding to what extent induction tasks may influence verbal information search within more complex environments.

The data were compared with those obtained in Vibert et al.'s (2019) first experiment, which assessed the influence of words that resembled the target word (orthographic distractors) or were semantically related to the target word (semantic distractors) on visual search for words within lists by adolescents, but did not assess the impact of induction tasks on the search process. Other differences between the two studies were that in the present experiment a comparison group of adult participants was included, and the search displays were created in such a way that the distance between words across the entire screen ensured that only one word could be foveated at a time, which was not the case when lists were used. In addition, the quality of participants' lexical representations (Perfetti & Hart, 2002; Perfetti & Stafura, 2014) was evaluated through three word-reading and vocabulary tests instead of only a single word-identification test. As in Vibert et al., the presence within the search displays of orthographic or semantic distractors was manipulated.

Influence of task demands and cognitive task-set on word processing

Whether in search lists, social network feeds or extended texts, access to target information depends on the reader's identification of words that match their search goals. Cascaded, activation-type models of word recognition assume that two different processing pathways may be used to identify a word: the *non-lexical* pathway, which consists of matching phonemes with the graphemes represented by the letters of the word, and the *lexical* pathway, which consists of directly using the semantic representations of words stored in memory to recognize the word. After a first perceptual analysis of the letters that compose the word, the reader may preferentially use one of the two pathways. Whereas young readers generally use the non-lexical pathway, older readers retrieve the orthographic, phonological, and semantic components of lexical representations synchronously and may use the two pathways simultaneously (Coltheart et al., 2001).

As a result, when skilled readers identify a word, its semantic associates as well as visually similar words may become primed in memory (Boot & Pecher, 2008; Carreiras et al., 1997; Heil et al., 2004; Rodd, 2004). Even though these processes are viewed as "automatic" and do not reach conscious awareness, the word-processing literature suggests that the way the visual form and meaning of written words are processed depends on task demands (Dampuré et al., 2014; Kiefer & Martens, 2010; Reichle et al., 2012; Vibert et al., 2019), and/or on the availability of attentional resources (Dampuré et al., 2019; Smith et al., 2001).

The task-dependency of lexical processing was formalized by Kiefer and Martens' (2010) theory of the attentional sensitization of unconscious cognition. They proposed that a particular word-identification pathway (i.e., through the words' orthography and phonology or through the words' meaning) can be sensitized and the other desensitized according to the nature of the verbal task to come. This proactive control of the "task-set" by the cognitive system would influence both conscious and unconscious processes. Kiefer and Martens assumed that the semantic word processing pathway (i.e., the lexical pathway) is used preferentially to access lexical representations when the meaning of words is particularly relevant for a task, whereas the perceptual word-processing pathway (i.e., the non-lexical pathway), which accesses lexical representations based on the words' visual form (i.e., their orthography and/or phonology), would be desensitized. In other words, Kiefer and Martens' theory assumes that the cognitive system can foster access to lexical representations of written words through either their visual form or their meaning according to the characteristics of the ongoing task.

In addition, the attentional sensitization theory predicts an impact of currently active task-sets on unconscious processing. In particular, previously performed verbal tasks should differentially sensitize the perceptual and semantic word-processing pathways according to which of the two pathways was the most relevant. Kiefer and Martens (2010) asked participants to perform an induction task, which involved either the meaning (semantic induction task) or the visual form (perceptual induction task) of words, before performing a lexical decision task that included subliminal semantic priming. The nature of the induction task strongly modulated subliminal word processing. For hundreds of milliseconds, subliminal semantic priming was larger after the semantic induction task and decreased after the perceptual induction task. Setting up a semantic task-set by performing a semantic induction task fostered the semantic word-processing pathways in subsequent verbal tasks, whereas performing a perceptual induction task fostered the use of perceptual word-processing pathways (Kiefer, 2012). As a plausible implication, performing either perceptual or semantic induction tasks before engaging in visual search for words may impact the way adolescents and adults process words during the search phase, and ultimately influence search efficiency.

Visual search for words by adolescents and adults

During visual search for words, people often have to actively scan a display to find the target word (Dampuré et al., 2014; Thornton & Gilden, 2007). When a distractor word is fixated, the searcher must reject it as quickly as possible using foveal vision, but must also decide where to look next according to what is perceived of the other words in the display. Because memorizing the target word primes the target's visual and semantic features in the mental lexicon, the words that have perceptual and/or semantic features in common with the representation of the target word kept in memory attract the searcher's attention (Dampuré et al., 2014; Vibert et al., 2019). According to models of visual search (Wolfe et al., 2011; Zelinsky, 2008), the attended/fixated item must reach awareness to be classified as a distractor or a target. In contrast, the features that guide the searcher's attention to particular items in the peripheral visual field do not always reach conscious awareness (Huettig et al., 2011; Soto et al., 2005; Van Zoest & Donk, 2010), which means that part of attention guidance within the display results from automatic, unconscious processes.

Only a few studies have used eye-movement recordings to assess the impact of orthographic and semantic distractor words on visual search for target words within lists (Léger et al., 2012; Vibert et al., 2019) or displays in which words are distributed across the screen (Dampuré et al., 2014; Zhou et al., 2017). The number of gazes directed towards each distractor word during the search process was taken as evidence of their ability to attract people's attention when perceived in the peripheral visual field, while gaze durations informed the amount of processing needed to reject the words at which the person gazed (Zelinsky, 2008).

Eye-tracking evidence corroborates the influence of words' features on people's visual exploration of verbal displays. When orthographic distractors were present, adults' and adolescents' search times greatly increased (Dampuré et al., 2014; Vibert et al., 2019), because orthographic distractors were gazed at more often and for longer durations than other words. Interestingly, semantic distractors were also gazed at a greater number of times than target-unrelated words (Dampuré et al., 2014; Vibert et al., 2019), probably because they became activated when participants learned the target word. In contrast, they were not gazed at for longer durations than other words, because they did not resemble the target word and were thus easily rejected. Vibert et al. (2019) also examined the effect of ageing on adolescents' visual search for words. Participants' search times decreased between the ages of 11 and 15 years, because older adolescents directed fewer gazes to distractor words and also gazed at them for shorter durations.

The role of lexical quality in adolescents' visual search for words

Learning to decode written words plays a central role in children's reading development (Perfetti, 1992; Plaut & Booth, 2000; Stanovich, 1980). The progressive automation of word decoding up until the age of 12 years may free mental resources for processing the words seen in the parafoveal/peripheral visual field during visual search for verbal information. The lexical quality hypothesis (Perfetti & Hart, 2002) assumes that mental representations of words include three main components, i.e., their orthographic, phonological, and semantic features. Another component refers to the strength of the connections between these features (Perfetti, 2007; Verhoeven et al., 2011; Verhoeven & Perfetti, 2011). High-quality lexical representations are based on well-specified orthographic, phonological, and semantic components that are strongly connected to one another. According to the lexical quality hypothesis, less skilled readers do not retrieve all components of lexical representations synchronously during word recognition (Nation, 2009; Perfetti & Hart, 2002). However, as children get older, they progressively acquire higher quality lexical representations that facilitate a flexible use of the different features of words to access lexical representations (Perfetti, 2007; Verhoeven & Perfetti, 2011).

Prior research suggests that the better quality of older adolescents' lexical representations facilitates the use of both the perceptual and the semantic features of words for top-down guidance during visual search for words (Vibert et al., 2019). In particular, older adolescents were better able to reject words without gazing at them directly. Therefore, young adolescents' difficulties in searching lists of verbal information, as one could access via search engine results pages, may result from insufficiently developed word-decoding abilities and lexical representations.

The current experiment

The main goal of this study was to find out whether performing either a perceptual or a semantic induction task before searching for a target word impacted the moment-by-moment ways that adolescents and adults processed words during the search phase. According to Kiefer and Martens' (2010) theory, performing induction tasks before the search may impact both the processes involved in the rejection of distractor words and the "automatic" attention guidance processes that determine the order in which words are gazed at within the search display.

Fifth, seventh, and ninth graders – as well as adults – were provided with a target word, with which they had to perform either a perceptual or a semantic induction task. Each target word was an example of a category (e.g., "bird" for the target word "raven"). In the perceptual task, participants had to say whether the target word contained the letter "o," and then to spell it aloud. In the semantic task, participants were asked to give two other examples of the target word's category (i.e., two other birds' names in the present case). Then, participants were tasked to search for the target word amongst eight other words, which could include orthographic or semantic distractors. Participants' search times were assessed as a function of age group, induction task, and the type of distractors included in the search display. Participants' eye movements were recorded during the search phase, and were analyzed by assessing the number and average duration of gazes directed towards non-target words before the participant clicked on the target word. Because displaying the words in vertical lists constrained the search strategy and limited the impact of word features on attention guidance (Léger et al., 2012; Ojanpää et al., 2002), word displays in which only one word could be foveated at a time were used (Dampuré et al., 2014). In addition, participants had to perform a word-identification test, a vocabulary test, and a category fluency test, which were combined to obtain a composite score that was used as an estimate of lexical quality.

Performing a semantic rather than a perceptual induction task on the target word should foster access to the lexical representations of words through their meanings, rather than through their visual form, during the search process. According to the feature-integration theory of visual search (Treisman & Gelade, 1980; see also Wolfe, 2020), the simplest visual features of the letters that make up the words, in particular their first and last letters, may be first quickly processed in parallel across the whole search display. Then, the binding of these simple features into recognizable and meaningful words would require a serial deployment of attention across the display. When the target word is known in advance, using the perceptual word-processing pathway when scanning the display should facilitate quick rejection of non-target words, which, for instance, can be rejected as soon as the features of their first or last letter differs from those of the target word's first or last letter. In contrast, fostering the semantic word-processing pathway should slow down the search process, because accessing the meaning of non-target words takes more time and, in most cases (except maybe for orthographic distractors), is not necessary to reject them.

Hence, the first hypothesis (H1) was that the perceptual induction task should decrease the duration of gazes directed to non-target words and accelerate the search process compared to the semantic task. Conversely, performing the semantic task rather than the perceptual task may increase the number of gazes directed to non-target words by prompting participants to get the meaning of each word. The second hypothesis (H2) was that performing the semantic task should promote the activation of the semantic associates of the target word, while reducing the activation of orthographically similar words. As a result, the semantic task should induce a particularly strong increase in the number and/or average duration of gazes directed to non-target words compared to the perceptual task when semantic distractors are present in the display. A third hypothesis (H3) was that the time needed to find target words should decrease with age, because of a decrease in both the number and the average duration of gazes directed to non-target words. The fourth hypothesis (H4) was that progress in visual search efficiency should be associated with an increase in the quality of participants' lexical representations. As such, the participants displaying higher lexical quality scores should find the target words faster because of a decrease in both the number and the duration of gazes directed to non-target words.

Beyond these formal hypotheses, eye-movement data were used as an exploratory tool to obatin more information about the cognitive mechanisms underlying the impact of induction tasks for each age group.

Material and methods

Participants

All participants were native French speakers and had normal or corrected-to-normal vision. They included 24 fifth graders (*M* age = 10.9 years, *SD* = .3; nine females), 24 seventh graders (*M* = 12.5 years, *SD* = .4; 13 females), 30 ninth graders (*M* = 14.8 years, *SD* = .4; 16 females), and 24 young adults (*M* = 27.5 years, *SD* = 3.8; 12 females). For adolescent participants, the experiment was conducted in five different schools in a medium-sized French town. Permission was sought from the school, the teacher, and from all students' parents or legal guardians by sending a parental consent form. After written and informed permission was obtained, all students were read a verbal script and were asked to assent to their participation in the study. The 24 adult participants were volunteers who provided their written informed consent before the study. They were recruited from the general population by word of mouth. They were selected according to both their gender and level of education in order to get a representative sample of the various levels of education reached by average populations of French female and male ninth graders according to the French National Institute for Statistics and Economic Studies (INSEE).[1] As such, the sample included three women and three men who quit school after 10 or 11 years of education and did not get a high school degree, four men and three women who stopped studying after completing their high school degree (after 12 years of education in France), three men and four women who went to university for 1–3 years and therefore had 13–15 years of education, and two men and two women who had Master's degrees and had therefore 17 years of education.

Apparatus

Participants' eye movements were recorded using a TOBII 1750 eye tracker as in Vibert et al. (2019). The eye tracker provided gaze positions at a sampling frequency of 50 Hz. The distance between participants' eyes and the eye-tracker was adjusted to get the best eye-detection and eye-movement recordings as possible for each participant. Depending on the participants, the optimal viewing distance varied between 477 and 817 mm. As a result, 10 mm on the screen of the eye tracker covered .70–1.20° of visual angle depending on participants. Léger et al. (2012) estimated the effective precision of this eye tracker at *M* = .54° of visual angle (*SD* = .30), which in this experiment corresponded to 4.5–7.7 mm on the screen depending on the viewing distance.

Visual search material

The visual search material was composed of 96 sets of nine common French nouns. The nine words included a target word and eight other words and were displayed together in black against a white background. All words were written in lower case letters in Arial font. In order to ensure some homogeneity in the verbal material, all 624 words used in the sets of words had four to 11 letters and two or three syllables. Most of them (620/624; 99.4%) had a lexical frequency greater than two per million in corpora of third- to fifth-grade readers used in French elementary schools, according to the Manulex (Lété et al., 2004) and/or Novlex (Lambert & Chesnet, 2001) databases. The lexical frequency of the four last words varied between 1.0 and 1.5 per million, because it was sometimes difficult to find sufficient numbers of semantic or orthographic distractors that fitted with the minimum lexical frequency criterion

Creation of word sets

The 96 word sets included 72 experimental sets and 24 filler sets. The 72 experimental sets were built around 24 target words (i.e., three sets per target word) as in Vibert et al. (2019). Each target word was an exemplar from a category (see Vibert et al., 2019, for details), which was used in the semantic induction task to prompt participants to produce their own exemplars of the category (Table 1). For instance, "corbeau" (raven) was an exemplar of "oiseau" (the bird category). Three different nine-word sets were built around each of the 24 target words as follows (Table 2):

- The "orthographic set" included the target word, four orthographic distractors that shared at least the first and last two letters with the target word, and four filler words that were unrelated to the target word.
- The "semantic set" included the target word, four semantic distractors that were semantically related to the target word (Léger et al., 2012), and the same four filler words as in the orthographic display.
- The "neutral set" included the same four filler words as in the previous sets and four additional neutral distractor words that were also unrelated to the target word.

The 408 words used in the experimental sets of words had *M* = 7.00 letters (*SD* = 1.31) and *M* = 2.26 syllables (*SD* = 0.45). There was no significant statistical difference in

[1] At the time the experiment was conducted, full review and approval of the study by an ethics committee or an Institutional Review Board was not required according to institutional and national guidelines and regulations. The experiment was conducted according to the ethical guidelines of the Declaration of Helsinki.

Table 1 List of the 24 target words used to build the experimental word sets. Each target word was an exemplar from a category, which was used in the semantic induction task as described in the "*Material and methods*" section. The original French target words are presented together with their translation

Target word	Category	Target word	Category
corbeau (raven)	bird	abeille (bee)	insect
anémone (anemone)	flower	poupée (doll)	toy
chemise (shirt)	clothing	requin (shark)	fish
salade (salad)	vegetable	poignard (dagger)	weapon
serpent (snake)	reptile	couteau (knife)	utensil
armoire (wardrobe)	piece of furniture	salon (lounge)	room
perceuse (drill)	tool	mouton (sheep)	animal
champagne (champagne)	drink	acier (steel)	metal
bassine (basin)	container	mandarine (mandarin)	fruit
poumon (lung)	organ	sculpteur (sculptor)	artist
essence (petrol, gas)	liquid	pétrolier (tanker)	boat
camion (truck, lorry)	vehicle	baignade (bathing)	leisure

Table 2 Experimental word sets built around the target word "corbeau" (raven)

Type of words	Neutral set		Orthographic set		Semantic set	
	French words	Translation	French words	Translation	French words	Translation
Target word	corbeau	raven	corbeau	raven	corbeau	raven
Distractor words	action	action	cadeau	present	branchage	branches
	grimace	grin	carreau	tile, pane	forêt	forest
	liaison	link	chameau	camel	perchoir	perch
	paupière	eyelid	ciseau	scissors	plumage	plumage
Filler words	basket	basket-ball	basket	basket-ball	basket	basket-ball
	moyenne	average	moyenne	average	moyenne	average
	roulette	roulette, caster	roulette	roulette, caster	roulette	roulette, caster
	serrure	lock	serrure	lock	serrure	lock

lexical frequency (Kruskal-Wallis ANOVA, $H(4, N = 408) = 8.30$, $p = .08$) between the target words ($M = 25.2$ per million, $SD = 20.6$, $Mdn = 21.6$), the filler words ($M = 22.0$, $SD = 24.4$, $Mdn = 11.3$), the neutral distractor words ($M = 29.5$, $SD = 38.3$, $Mdn = 13.3$), the semantic distractor words ($M = 40.1$, $SD = 63.9$, $Mdn = 21.9$) and the orthographic distractor words ($M = 21.1$, $SD = 29.8$, $Mdn = 9.7$) across the 24 target words. There was also no significant difference in the number of letters (Kruskal-Wallis ANOVA, $H(4,N = 408) = 3.38$, $p = .50$), number of syllables ($H(4,N = 408) = 7.79$, $p = .10$) and number of orthographic neighbors ($H(4,N = 408) = 7.24$, $p = .12$) between the target words, the filler words and the three types of distractor words.

Construction of search displays

In the search displays, the nine words of each set were arranged to maximize the distance between the words while avoiding horizontal or vertical alignments. A unique nine-word arrangement was built for each target word within a six-line by five-column grid. The grid was divided into five areas, i.e., a central cross-like area and four peripheral, corner-like areas (Fig. 1A). The nine words were randomly assigned to nine cells in the grid, under the condition that there had to be a minimum of one word in each of the five areas. The target word had to be located in one of the four peripheral areas in order to maximize the impact of the distractor words. Of course, the grid that was used to build the display was invisible to participants (panels B and C of Fig. 1).

The resulting nine-word arrangement was used to generate the three experimental displays in which this target word was searched. Importantly, the positions of the target word and the four filler words were held constant across the three displays. The positions of the four set-specific distractor words were also the same in the three sets, but their nature (orthographic, semantic, or neutral) changed according to set type (Table 2 and Fig. 1).

In the 72 experimental word displays, the four neutral, orthographic, or semantic distractors were written in large 24-point Arial font (9 mm in height on the eye-tracker screen), whereas the target word and filler words were written in smaller 14-point font (5.5 mm in height) in order to maximize the impact of distractor words (Fig. 1). The distance between the center of each word and that of its closest neighbor was at least 35 mm, i.e., much higher than the effective precision of the eye tracker (see above). Since the human fovea covers 2.0° of visual angle, i.e. 16.6–28.6 mm on the screen depending on the distance from it at which they sat, the participants could only foveate one word at a time.

Twenty-four filler displays, which were different from the experimental displays, were used in this experiment. In these displays, which were not considered in data analyses, most of the target words (16 out of 24) were placed within the cross-like central area. The filler trials were interspersed between the experimental trials to prevent participants from immediately searching for the target word in the peripheral areas. As in the experimental displays, the set-specific distractor words were written in large font, whereas the filler words were written in smaller font. In 16 of the filler displays, however, the target word was written, as the distractor words, in large font, to prevent participants from immediately searching for the target word within the words written in smaller font.

Lexical quality tests

The quality of participants' lexical representations was evaluated by combining a measure of their word identification speed, a verbal fluency test, and a vocabulary test. As the three scores were all correlated with each other (all rs > .54, all ps < .001), z-scores for each separate test were aggregated into one score per individual (see below).

Word identification speed

Participants' word identification speed was measured using the "Pipe and Rat" test (Lefavrais, 1968). Participants silently read words displayed on successive lines with articles (beginning with "the pipe – the rat –..."). They had to read as many words as possible within 3 min. Half of the words were animal names and participants were asked to underline all of them while reading. The number of correctly identified animal names minus the number of incorrectly underlined names was an index of word identification speed.

Category fluency task

The speed of participants' access to their mental lexicon was measured using a category fluency task, in which participants were given 1 min to produce as many different words as possible belonging to a particular semantic category, here the "animals" category. The participants' score was the number of words produced in 1 min.

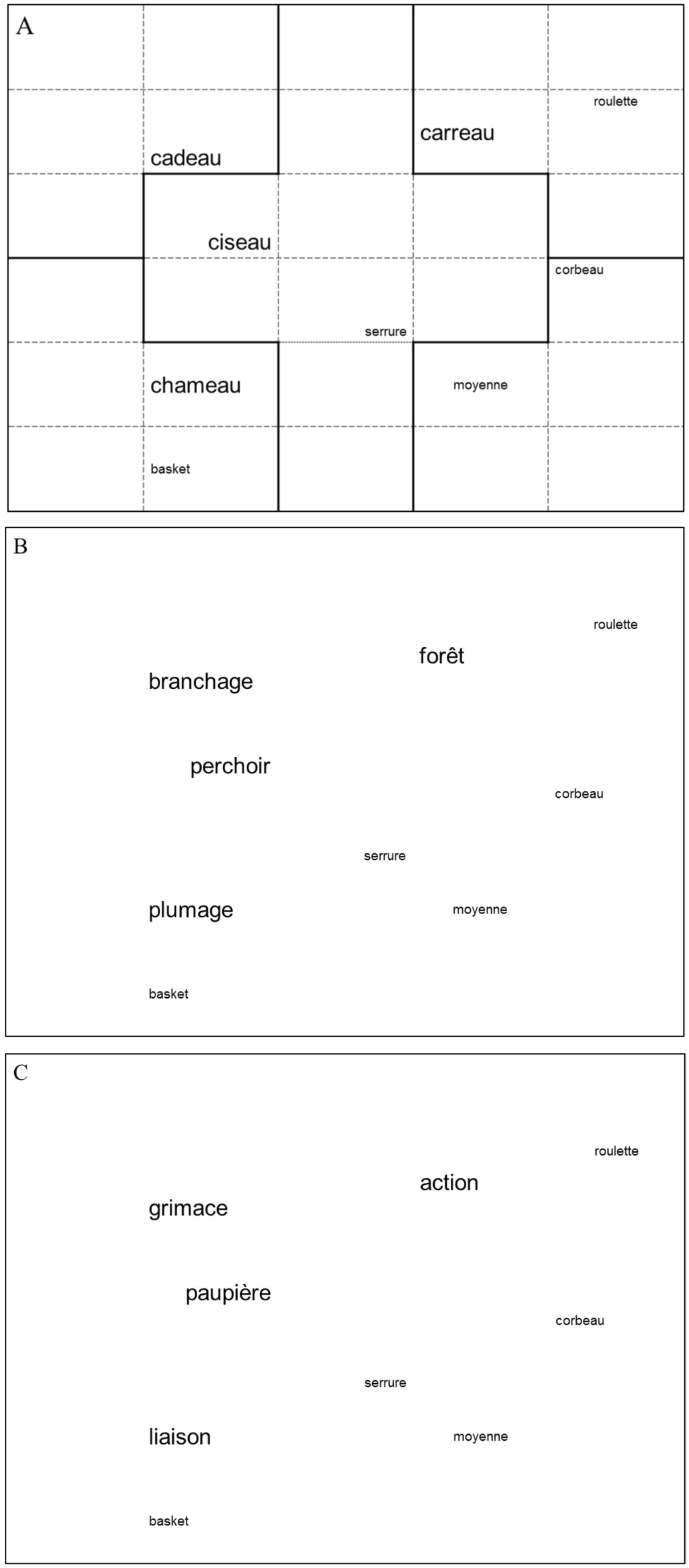
Vocabulary test

Participants' vocabulary knowledge was assessed using a French adaptation of the Mill Hill vocabulary test (Deltour, 1993). Only the second part of the test, in which participants must recognize the meanings of successive words by choosing the correct synonym for each word from among six options, was used in the present study, in a child-adapted version that included 33 items of increasing difficulty. The score was the number of words for which the correct synonym was chosen.

Design and procedure

For the visual search task, participants were tested individually in a single session that included two blocks of 24 trials each. Participants searched for target words after performing the perceptual induction task in one block, and after performing the semantic task in the other block. Half of the participants began with the perceptual task, whereas the other half began with the semantic task. In each block, participants were presented with three practice trials, followed by 12 experimental and 12 filler trials in random order. The assignment of the 24 target words between the two induction tasks and the three different types of display was counterbalanced so that the type of display and induction task factors were crossed with six sets of four target words and groups of six participants. As a result, each participant searched once for each of the 24 experimental target words in an orthographic, semantic, or neutral display, following either the perceptual or the semantic induction task (four trials per condition).

Each trial began with a slide showing a central fixation cross, on which the participant had to position the mouse cursor. When the experimenter pressed a key, the target word (e.g., raven) appeared at the center of the screen. When participants had to perform the perceptual induction task, the experimenter read the word aloud, and asked the participant first to say whether the word contained the letter "o," and second to spell aloud the word letter by letter. For the semantic induction task, the experimenter told participants that the target word was an example of a particular category and asked them to give two other examples of this category. Then, a screen showing the display in which the participant


A
roulette
carreau
cadeau
ciseau
corbeau
serrure
chameau
moyenne
basket
B
roulette
forêt
branchage
perchoir
corbeau
serrure
plumage
moyenne
basket
C
roulette
action
grimace
paupière
corbeau
serrure
liaison
moyenne
basket

◂**Fig. 1** Example of search displays for the target word "corbeau" (raven). **A**. Example of orthographic display showing the grid (dotted lines) and five main areas (boldface lines) used to distribute the words. **B**. Example of semantic display. **C**. Example of neutral display

was to locate the target word appeared. Participants were instructed to find the target word as quickly as possible, but without making mistakes. They were also instructed not to move the mouse cursor before having located the target word, but then to click on it as soon as they had found it. The response time was the time that elapsed between the appearance of the word display and the participant's click on the target word.

To control for individual differences in mouse control ability, each participant performed a speeded mouse-pointing task once before beginning the visual search experiment, and once at the end of the experimental session. The task included five trials in which the participant had first to position the mouse cursor on a central fixation cross. Then, a word-size horizontal rectangle, which was located at a position where target words could be displayed in the experimental trials, appeared on the screen. The participant had to move the mouse and click within the rectangle as quickly as possible. The location of the rectangle was different on each trial. The "motor reaction time" was computed as the time that elapsed between the appearance of the rectangle and the moment the participant clicked in it.

After the visual search task, seventh graders, ninth graders, and adults performed individually the word identification test, the verbal fluency task and the vocabulary test, in that order. Fifth graders performed individually only the verbal fluency task and the vocabulary test. The word identification test was administered simultaneously to the whole class group.

Eye-movement recordings

The ClearView 2.7.1 software was used to record eye movements and to time slide presentations and mouse clicks. Eye fixations were defined as any period where gaze stopped for 60 ms or more within a 10 mm (about 1.0° of visual angle) diameter area. During the search, a fixation was assigned to a word when it was located within 20 mm of the word, i.e. the distance covered by the participant's fovea. Fixations that were not located within 20 mm of any word were removed from the analysis. Successive fixations on the same word were collapsed together as one "gaze" at this word.

Data analyses

Visual search data

The median "motor reaction time" obtained by each participant on the two mouse-pointing tasks was subtracted from their raw response time to isolate participants' "search time". Participants' performance was assessed using error rate and search times as dependent variables. All trials where errors were made were excluded from further analyses. Search times and eye-movement data were analyzed using linear mixed models that were obtained using the JASP software (version 0.16.0.0). Each model included participants and items as random intercepts, and as many as possible by-participant and by-item random slopes. Satterthwaite approximation for degrees of freedom were used to obtain the F values, probabilities and effect sizes. All follow-up pairwise comparisons were performed based on adjusted least squares means, using t-tests and dummy contrast coding, with the two levels to be compared set to -1 and 1, respectively.

A logarithmic transformation was applied to search times, which were then analyzed using age group, induction task (perceptual or semantic), and type of display (neutral, semantic, or orthographic), and their interactions as fixed factors, and participants and items as random intercepts. Participants' eye movements were analyzed using the number and average duration of gazes directed to non-target words before the participant clicked on the target word. Analyses of eye movements were conducted using age group, induction task, type of display, and type of word (filler words or distractor words), and their interactions as fixed factors, and participants and items as random intercepts.

Evaluation of the quality of participants' lexical representations

To obtain a single "lexical quality" score combining the scores obtained on the three tests by each participant, a composite variable was created by standardizing each score over the whole population of participants, and then summing the three z-scores obtained for each participant. Because lexical quality scores depended strongly on participants' age (see below), multivariate linear regression models were designed to check whether participants' quality of lexical representations and/or age could predict search times and eye-movement data.

Results

Visual search task

Error rates

The error rate was very low for all age groups, since participants made only 17 target selection errors over the 2,448 experimental trials (.7% error rate). The error rate was .2% in ninth graders, .3% in adults, 1.8% in seventh graders, and 2.1% in fifth graders.

Table 3 Participants' mean visual search times (in ms) as a function of age group, induction task and type of display. Standard deviations are provided within parentheses

Age group and induction task	Type of display			
	Neutral	Orthographic	Semantic	All displays
Fifth graders				
Perceptual task	1,971 (684)	2,734 (1,129)	2,016 (558)	2,226 (581)
Semantic task	2,596 (1,254)	3,038 (1,325)	2,408 (819)	2,675 (971)
Both tasks	2,281 (812)	2,876 (1,114)	2,210 (567)	2,448 (733)
Seventh graders				
Perceptual task	2,077 (1,505)	2,432 (863)	1,924 (713)	2,145 (781)
Semantic task	2,347 (818)	2,747 (1,369)	2,191 (712)	2,430 (805)
Both tasks	2,209 (881)	2,595 (1,021)	2,066 (554)	2,289 (690)
Ninth graders				
Perceptual task	1,353 (346)	1,716 (444)	1,380 (295)	1,483 (238)
Semantic task	1,423 (350)	1,926 (477)	1,654 (438)	1,667 (292)
Both tasks	1,388 (267)	1,822 (364)	1,517 (288)	1,575 (218)
Adults				
Perceptual task	1,389 (412)	1,672 (454)	1,334 (299)	1,465 (306)
Semantic task	1,557 (474)	1,796 (594)	1,724 (637)	1,694 (403)
Both tasks	1,473 (396)	1,736 (417)	1,529 (406)	1,579 (321)
All participants				
Perceptual task	1,389 (412)	1,672 (454)	1,334 (299)	1,810 (617)
Semantic task	1,557 (474)	1,796 (594)	1,724 (637)	2,090 (789)
Both tasks	1,811 (744)	2,232 (915)	1,812 (550)	1,949 (655)

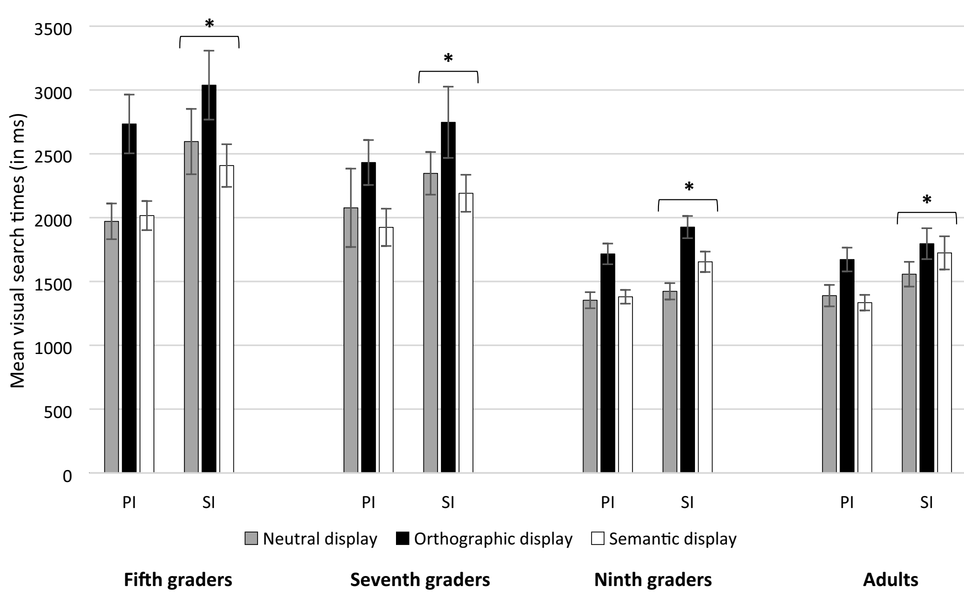


Fig. 2 Participants' mean search times (in ms) as a function of age group, induction task, and type of display. Error bars represent standard errors of the means. *PI*: perceptual induction task, *SI* semantic induction task. The asterisks (*) indicate the search times that were significantly longer after the semantic induction task than after the perceptual one

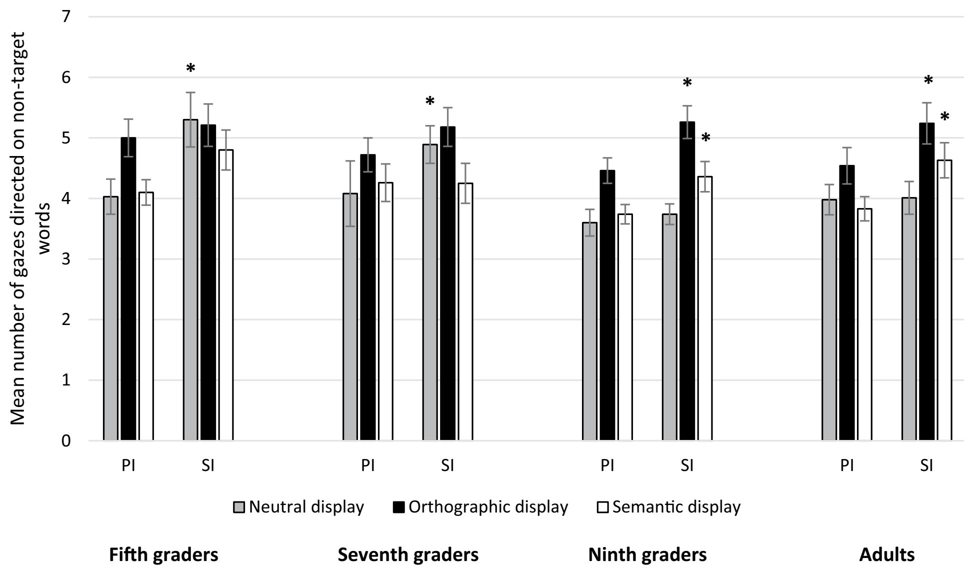


Fig. 3 Participants' mean number of gazes directed to non-target words (both filler words and distractor words) as a function of age group, induction task, and type of display. Error bars represent standard errors of the means. *PI* perceptual induction task, *SI* semantic induction task. The asterisks (*) indicate the mean numbers of gazes which were significantly or marginally significantly longer after the semantic induction task than after the perceptual one

Search times

The model for search times (Table 3 and Fig. 2) revealed main effects for induction task ($F(1,21) = 26.40$, $p < .001$, $\eta_p^2 = .56$), age group ($F(3,97) = 29.82$, $p < .001$, $\eta_p^2 = .48$), and type of display ($F(2,31) = 15.27$, $p < .001$, $\eta_p^2 = .50$), with no significant interaction. As hypothesized (H1, Table 3 and Fig. 2), performing the semantic task increased participants' search times (by 15.5%) compared to the perceptual task. Also, as expected (H3, Table 3 and Fig. 2), the speed of visual search for words increased with age since fifth graders' search times were longer than ninth graders' ($t(97) = 7.34$, $p < .001$, $d = 1.49$) and adults' ($t(97) = 7.29$, $p < .001$, $d = 1.48$), and seventh graders' search times were longer than ninth graders' ($t(97) = 5.91$, $p < .001$, $d = 1.20$) and adults' ($t(97) = 5.93$, $p < .001$, $d = 1.20$). As in Vibert et al. (2019), the presence of orthographic distractors reduced search efficiency compared to instances where they were not present (Table 3 and Fig. 2). Indeed, search times were longer for orthographic displays than for neutral ($t(67) = 5.49$, $p < .001$, $d = 1.34$) and semantic displays ($t(24) = 3.60$, $p < .01$, $d = 1.47$). Contrary to expectations, however, participants' search times were not significantly different between semantic and neutral displays ($t(435) = 1.09$, $p = .28$).

Eye-movement data: number of gazes directed to non-target words

Participants gazed at about half of the non-target words and stopped searching as soon as the target word was fixated. The model for the number of gazes (Fig. 3) showed main effects for induction task ($F(1,34) = 14.84$, $p < .001$, $\eta_p^2 = .30$), age group ($F(3,94) = 3.19$, $p < .05$, $\eta_p^2 = .09$), type of display ($F(2,34) = 7.00$, $p < .01$, $\eta_p^2 = .29$), and type of word ($F(1, 24) = 8.10$, $p < .01$, $\eta_p^2 = .25$). There was an interaction between type of display and type of word ($F(2,4327) = 16.59$, $p < .001$, $\eta_p^2 = .008$), and a three-way interaction between age group, induction task, and type of display ($F(6,4339) = 2.47$, $p < .05$, $\eta_p^2 = .003$).

As hypothesized (H1, Fig. 3), performing the semantic task rather than the perceptual one increased the average number of gazes directed to non-target words (by 13%, 4.72 ± 1.09 gazes versus 4.18 ± .82). The main effect of grade revealed that, as expected (H3, Fig. 3), part of the increase in search speed with age was due to a decrease in the number of gazes directed to non-target words (Fig. 3), because fifth graders directed more gazes to non-target words (4.74 ± .93) than ninth graders (4.19 ± .47, $t(94) = 2.91$, $p < .01$, $d = .60$) and adults (4.37 ± .65, $t(94) = 1.96$, $p = .05$, $d = .40$), and seventh graders directed marginally more gazes to non-target words (4.56 ± .88) than ninth graders' ($t(94) = 1.94$, $p = .055$, $d = .40$).

The type of display by type of word interaction demonstrated that, as in Vibert et al. (2019), the increase in search times caused by orthographic distractors was due in part to an increase in the number of gazes directed to these distractors (Fig. 3). Indeed, participants directed more gazes to orthographic distractors (2.82 ± .82) than to neutral distractors (2.11 ± .62, $t(340) = 5.53$, $p < .001$, $d = .60$), whereas the numbers of gazes directed to semantic

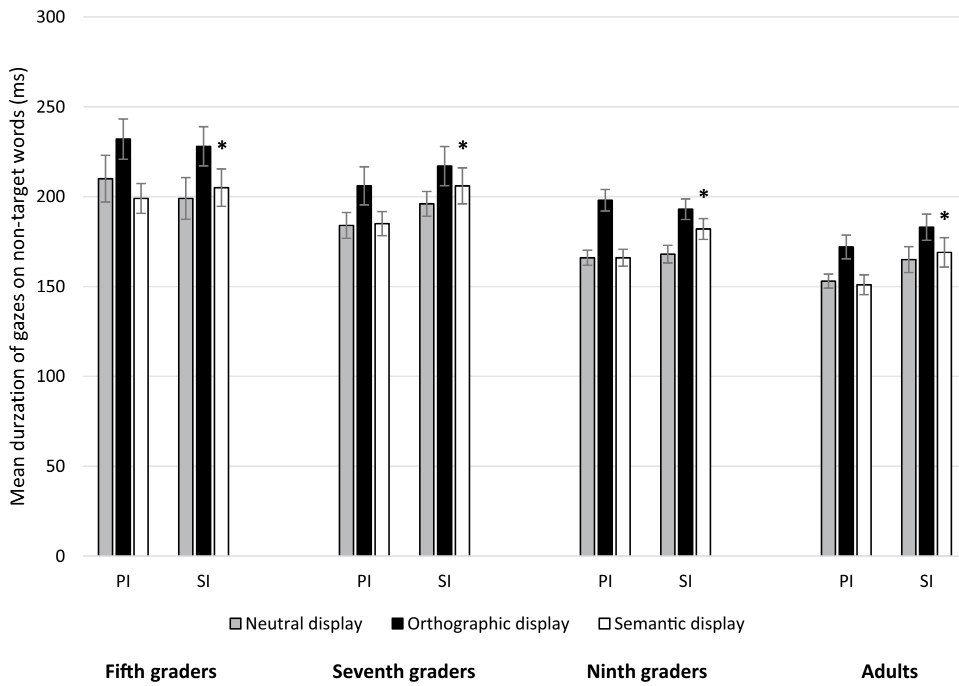


Fig. 4 Participants' mean duration of gazes (in ms) directed to non-target words (both filler words and distractor words) as a function of age group, induction task, and type of display. Error bars represent standard errors of the means. *PI* perceptual induction task, *SI* semantic induction task. The asterisks (*) indicate the mean durations of gazes which were significantly longer after the semantic induction task than after the perceptual one

(2.18 ± .63) and neutral distractors did not differ significantly ($t(340) = .58$, $p = .56$). In addition, participants gazed more often at orthographic distractors than at filler words (2.21 ± .60 gazes) in orthographic displays ($t(340) = 5.64$, $p < .001$, $d = .61$), whereas the filler words did not attract significantly different numbers of gazes in orthographic ($t(340) = .96$, $p = .34$) or semantic displays (2.08 ± .56, $t(340) = -.08$, $p = .94$) compared to neutral displays (2.07 ± .73).

The three-way interaction revealed in addition that the impact of induction tasks on the number of gazes directed to non-target words varied according to both age group and type of display (Fig. 3). In fifth graders and seventh graders, the semantic task induced a greater number of gazes directed to non-target words compared to the perceptual task for neutral displays (fifth graders: $t(4,330) = 3.59$, $p < .001$, $d = .11$, seventh graders: $t(4,330) = 2.27$, $p < .05$, $d = .07$), but not for semantic (fifth graders: $t(4,330) = 1.63$, $p = .10$, seventh graders: $t(4,330) = -.03$, $p = .98$) or orthographic displays (fifth graders: $t(4,330) = 1.20$, $p = .23$, seventh graders: $t(4,330) = 1.54$, $p = .12$). In contrast, ninth graders and adults directed more or marginally more gazes to non-target words after the semantic task than after the perceptual task for both orthographic (ninth graders: $t(4,330) = 2.75$, $p < .01$, $d = .08$, adults: $t(4,330) = 2.22$, $p < .05$, $d = .07$) and semantic displays (ninth graders: $t(4,330) = 1.74$, $p = .082$, $d = .05$, adults: $t(4,330) = 2.02$, $p < .05$, $d = .06$), but not for neutral displays (ninth graders: $t(4,330) = .39$, $p = .70$, adults: $t(4,330) = .06$, $p = .95$).

Eye-movement data: Average gaze durations

The model for average gaze durations (Fig. 4) revealed main effects for induction task ($F(1,82) = 14.34$, $p < .001$, $\eta_p^2 = .15$), age group ($F(3,97) = 10.82$, $p < .001$, $\eta_p^2 = .25$), and type of display ($F(2,37) = 17.01$, $p < .001$, $\eta_p^2 = .48$). They were qualified by interactions between type of display and type of word ($F(2,3792) = 46.00$, $p < .001$, $\eta_p^2 = .02$), induction task and type of display ($F(2,1935) = 3.91$, $p < .05$, $\eta_p^2 = .004$), induction task and age group ($F(3,106) = 3.16$, $p < .05$, $\eta_p^2 = .08$), and by a three-way interaction between induction task, age group, and type of word ($F(3,3784) = 2.80$, $p < .05$, $\eta_p^2 = .002$).

As hypothesized (H1, Fig. 4), performing the semantic task rather than the perceptual one induced a weak, but significant increase in participants' average gaze durations on non-target words (by 4.5%, 193 ± 38 ms vs. 185 ± 38 ms). Also, as expected (H3), the main effect of grade revealed that the increase in search speed with age was due in part to a decrease in the duration of gazes directed to non-target words (Fig. 4). Indeed, fifth graders' average gaze durations (216 ± 48 ms) were longer than ninth graders' (177 ± 22 ms, $t(97) = 3.87$, $p < .001$, $d = .79$) and adults' (164 ± 29 ms, $t(97) = 5.19$, $p < .001$, $d = 1.05$). Similarly, seventh graders'

Table 4 Participants' mean scores on lexical quality tests as a function of age group. Standard deviations are provided within parentheses

Lexical quality tests	Age group			
	Fifth graders	Seventh graders	Ninth graders	Adults
Word identification test	75 (17)	79 (16)	102 (32)	108 (21)
Category fluency task	19 (6)	18 (5)	21 (5)	24 (7)
Mill-Hill test	15 (4)	17 (4)	21 (4)	28 (4)
Composite lexical quality score	-1.70 (1.94)	-1.48 (1.71)	.48 (1.70)	2.58 (2.41)

gaze durations (195 ± 34 ms) were longer than ninth graders' ($t(97) = 2.35$, $p < .05$, $d = .48$) and adults' ($t(97) = 3.75$, $p < .001$, $d = .76$).

The type of display by type of word interaction confirmed that, as in Vibert et al. (2019), the increase in search times caused by orthographic distractors resulted in part from the longer duration of the gazes directed to these distractors (Fig. 4). Indeed, participants gazed longer at orthographic distractors (216 ± 54 ms) than at neutral distractors (175 ± 47 ms, $t(3,800) = 9.09$, $p < .001$, $d = .29$), whereas gaze durations on semantic (175 ± 37 ms) and neutral distractors did not differ significantly ($t(3,800) = .14$, $p = .89$). In addition, participants gazed longer at orthographic distractors than at filler words (190 ± 37 ms) in orthographic displays ($t(3,800) = 5.80$, $p < .001$, $d = .19$). Participants displayed similar gaze durations on filler words in orthographic ($t(3,800) = .95$, $p = .34$) and semantic displays (191 ± 38 ms, $t(3,800) = 1.30$, $p = .19$) compared to neutral displays (185 ± 39 ms).

The induction task by type of display interaction revealed that, in accordance with hypothesis 2, the semantic task significantly increased participants' gaze durations compared to the perceptual task for semantic displays only (190 ± 45 ms versus 174 ± 36 ms, $t(1,935) = 4.57$, $p < .001$, $d = .21$), i.e., only when semantic distractors were present in the display. In contrast, the increase was not significant for neutral (181 ± 41 ms vs. 177 ± 43 ms, $t(1,935) = 1.09$, $p = .28$) or orthographic displays (204 ± 47 ms vs.s 202 ± 48 ms, $t(1,935) = 1.79$, $p = .074$).

Finally, the three-way interaction revealed that regardless of the type of display, the impact of induction task on participants' gaze durations on non-target words varied according to both age group and type of word. In fifth graders, compared to the perceptual task, the semantic task did not significantly increase participants' gaze durations on either distractor words, whatever their type ($t(3,780) = 1.06$, $p = .29$), or filler words ($t(3,780) = -1.56$, $p = .12$). In seventh and ninth graders, the semantic task did not significantly increase participants' gaze durations on distractor words (seventh graders: $t(3,780) = 1.47$, $p = .14$, ninth graders: $t(3,780) = .55$, $p = .58$), but had an impact on participants' gaze durations on filler words (seventh graders: 205 ± 35 ms vs. 185 ± 41 ms, $t(3,780) = 3.70$, $p < .001$, $d = .12$, ninth graders: 186 ± 31 ms vs. 173 ± 27 ms, $t(3,780) = 1.78$, $p = .075$, $d = .06$). In adults, the semantic task increased participants' gaze durations on both distractor words (167 ± 36 ms vs. 157 ± 30 ms, $t(3,780) = 2.08$, $p < .05$, $d = .07$) and filler words (173 ± 34 ms vs. 158 ± 23 ms, $t(3,780) = 2.89$, $p < .01$, $d = .09$).

Lexical quality tests

Lexical quality scores (Table 4) revealed a main effect of age group ($F(3,98) = 25.38$, $p < .001$, $\eta_p^2 = .44$). Although lexical quality was not significantly different between fifth and seventh graders ($t(98) = .40$, $p = .69$), it was higher for ninth graders than for seventh graders ($t(98) = 3.66$, $p < .001$, $d = .74$), and higher for adults than for ninth graders ($t(98) = 3.95$, $p < .001$, $d = .80$). Altogether, there was a strong positive correlation between participants' lexical quality scores and age ($r = .62$, $p < .001$) across the whole sample of participants. According to published norms for the word identification test (Lefavrais, 1968), the current sample of fifth graders performed well over the grade-level norm (Table 4), which may explain why no significant difference in lexical quality was found between fifth and seventh graders.

Because of the strong positive correlation between participants' lexical quality scores and age, a multivariate regression model was designed to assess the respective impacts of lexical quality and age on participants' search times. The model was significant ($F(2,98) = 39.58$, $p < .001$, $\eta_p^2 = .45$) and revealed that, as hypothesized (H4), the participants displaying higher lexical quality scores found the target words faster ($\beta = -.56$, $SE = .10$, $p < .001$). The lexical quality scores explained 43% of the variance in search times independently of participants' age. The models obtained for eye-movement data were both significant ($F(2,98) = 3.62$, $p < .05$, $\eta_p^2 = .07$ for the number of gazes directed to non-target words, and $F(2,98)$

= 18.58, $p < .001$, $\eta_p^2 = .27$ for gaze durations). The participants displaying higher lexical quality scores directed less gazes to non-target words (β = -.25, SE = .10, $p < .05$) and gazed at them for shorter durations (β = -.50, SE = .09, $p < .001$). However, lexical quality scores explained only 6% of the variance in the number of gazes directed to non-target words, versus 24% of the variance in gaze durations. Hence, the decrease in participants' search times associated with higher lexical quality was mainly caused by a decrease in gaze durations on non-target words.

Overall data summary

As hypothesized (H1), performing the semantic task increased participants' search times compared to the perceptual task. This increase was due mainly to an increase in the number of gazes directed to non-target words, but also to a slight increase in their average duration. In addition, the speed of visual search for words increased with age (H3) because both the number and duration of gazes directed to non-target words decreased, and the presence of orthographic distractors reduced search efficiency compared to instances where they were not present.

In addition, eye-movement data revealed that the impact of the semantic task on the number of gazes directed to non-target words was stronger for neutral displays than for orthographic or semantic displays in fifth and seventh graders, whereas the reverse was true for ninth graders and adults. Regarding the duration of gazes directed to non-target words, the induction task by type of display interaction showed that (H2) the semantic task had a significant impact on gaze durations only when semantic distractors were present, i.e., for semantic displays, but not for neutral or orthographic displays. The three-way interaction between induction task, age group, and type of word demonstrated that the impact of the semantic task on the duration of gazes directed to non-target words progressively extended from filler words to distractor words with age.

Finally, participants displaying higher lexical quality scores found the target words faster (H4), because they directed less gazes to non-target words and gazed at them for shorter durations. Participants' lexical quality scores explained 43% of the variance in search times, but only 6% of the variance in the number of gazes directed to non-target words versus 24% of the variance in gaze durations. Since performing the semantic task rather than the perceptual one increased the number of gazes directed to non-target words by 13%, but the average duration of these gazes only by 4.5%, induction tasks had a stronger impact than lexical quality scores on the number of gazes directed to non-target words, whereas lexical quality scores had a much stronger impact than induction tasks on the average duration of these gazes.

Discussion

Impact of induction tasks on visual search for words

The experiment examined the impact of a semantic versus a perceptual induction task on the search for target words within simple displays. As hypothesized (H1), irrespective of the age of participants, performing the semantic induction task increased the time needed to find the target word relative to the perceptual one because of an increase in both the number and average duration of gazes directed to non-target words. In accordance with Kiefer and Martens' (2010) attentional sensitization theory, performing induction tasks before the search impacted both the processes involved in the rejection of distractor words and the "automatic" attention guidance processes that determine which words are gazed at in the search display. The large extent and the strength of the differential impact of semantic versus perceptual induction tasks on such a simple visual search task supports the idea that semantic induction tasks may also have an impact in more complex verbal environments.

In accordance with H3, performing induction tasks on the target words did not substantially modify the development of search efficiency with age, which was similar to that reported in previous studies (Dampuré et al., 2014; Léger et al., 2012; Vibert et al., 2019). As in Vibert et al., participants' search times decreased from fifth to ninth grade because older students fixated non-target words for less time, but also because they directed fewer gazes to non-target words. Interestingly, the efficiency of visual search for words showed no further increase between ninth grade and adulthood when adult participants were recruited from the general population as in this study.

The impact of orthographic distractors was similar to what was obtained in previous studies (Dampuré et al., 2014; Léger et al., 2012; Vibert et al., 2019). The presence of orthographic distractors increased search times both because they attracted more gazes than the other types of words and because they had to be gazed at for longer durations before being rejected. Semantic distractors, in contrast, did not induce a significant increase in search times and/or of the number of gazes directed to non-target words, as they did in Léger et al. (2012) and Vibert et al. (2019). This could be due to the mode of presentation of words in the search display, since in Léger et al.'s and Vibert et al.'s studies the target words were searched within vertical lists of words, whereas random displays were used in this study. Indeed, Dampuré et al. did not find any significant impact of semantic distractors on search times for adult participants searching through random displays of words. However, there was also a discrepancy with Dampuré et al.'s findings, in which semantic distractors attracted more gazes than neutral distractors and filler words, because in the present findings semantic distractors did not attract attention significantly more than other words. This discrepancy may result from the fact that in Dampuré et al., adult participants were mostly university students, who may have particularly high literacy skills, while in this study adult participants were recruited from the general population with varied educational levels. Several authors demonstrated that variability of literacy skill in adulthood was associated with differences in lexically driven eye-movement control during reading (Payne et al., 2020). Veldre and Andrews (2015) suggested that readers with higher quality lexical representations were more likely to extract lexical information from a word before it is fixated. Hence, in the present situation, semantic distractors might only have an impact on visual search for people having high quality lexical representations.

Modulation of the impact of induction tasks as a function of age group and type of distractors present in the search display

Eye-movement data revealed that the impact of induction tasks was not the same for all groups of participants, and that, as hypothesized (H2), the impact of semantic distractors varied according to the induction task performed on the target word.

Firstly, the increase in the number of gazes observed after performing the semantic rather than the perceptual task was stronger for neutral displays than for orthographic or semantic displays in fifth and seventh graders, whereas the reverse was true for ninth graders and adults. For the youngest adolescents, performing the semantic task may have led participants to gaze at each word in the display to try to get its meaning even when the words did not share any feature with the target word, resulting in a particularly strong increase in the number of gazes in neutral displays. Ninth graders and adults, by contrast, were able to more easily reject the non-target words that did not share any feature with the target word using their parafoveal/peripheral vision, potentially because of the better quality of their lexical representations. Therefore, performing the semantic induction task may have encouraged them to have more systematic access to the meaning of a more restricted set of words, i.e., the orthographic and semantic distractors that shared features with the target word. In addition, the ninth graders' and adults' data support the hypothesis (H2) that performing the semantic task rather than the perceptual one increased the impact of semantic distractors on the attentional guidance process.

Secondly, the impact of the semantic task on the duration of gazes directed to non-target words progressively increased with age. Indeed, performing the semantic task did not have any significant impact on fifth graders' gaze durations, whereas it induced a large increase in gaze durations in ninth graders and adults. Because of their lower word decoding abilities (Perfetti, 1992; Plaut & Booth, 2000; Stanovich, 1980), fifth graders may need to access the meaning of distractor words to reject them even after performing the perceptual task or in the absence of any induction task. This would explain why, for them, performing the semantic task did not induce any significant increase in gaze durations. For the older participants, by contrast, performing the semantic rather than the perceptual task guided participants towards processing more deeply than necessary the non-target words, thus increasing the duration of their gazes.

Thirdly, whatever the participants' age, the impact of the semantic task on the duration of gazes directed to non-target words was greater for semantic displays than for neutral or orthographic displays. Performing the semantic induction task, as expected (H2), potentiated the impact of semantic distractors on the distractor rejection process by increasing the interference between semantic distractors and the target word. However, performing the perceptual induction task did not increase the impact of orthographic distractors, maybe because when the target word is known in advance, orthographic distractors are already maximally salient even when no induction task is performed.

Impact of lexical quality scores on visual search for words

In accordance with hypothesis 4, the increase in visual search efficiency with age was strongly related to the progressive increase in the quality of adolescents' lexical representations. Indeed, participants' lexical quality scores explained 43% of the variance in search times independently of participants' age. Interestingly, the decrease in participants' search times associated with higher lexical quality scores appeared to result more from a decrease in the duration of gazes directed to non-target words than from a decrease in their number. Hence, making a flexible use of the different word processing pathways that may be used to access lexical representations would have an impact on visual search efficiency primarily by shortening the time needed to reject the distractor words sharing features with the target word. Better lexical quality scores also allowed participants to more easily reject non-target words without fixating them directly, i.e., using parafoveal/peripheral vision, but this facilitation of attention guidance had a weaker impact on visual search efficiency.

Implications for visual search in more complex verbal environments

As expected, in the simple visual search task used in the present study, fostering access to the lexical representations of words through meanings slowed down visual search, because accessing the meaning of non-target words was not necessary and delayed their rejection. However, fostering semantic word processing through semantic induction tasks could in contrast have a beneficial impact on information search and use in more complex verbal environments where the meaning of words must be accessed to find task-relevant information. Performing semantic induction tasks may for instance facilitate visual search for answers to inferential questions in texts by helping adolescents consider the meaning of the text. The strong impact of semantic induction tasks observed in this study suggests that such tasks may be a powerful tool to facilitate verbal information search in more ecologically-valid situations where the exact wording of the information to find is unknown.

One limitation of the current work is that in daily life, people do not often search for single words through random word displays, which questions the generalizability of the data. Rouet et al. (2011) demonstrated that reading a short text about the search topic before performing a Web-like search helped young adolescents to select semantically relevant menu entries. This suggests that semantic induction tasks may also facilitate information search in this situation. However, the extent to which performing semantic induction tasks before searching for verbal information in more diverse natural contexts will actually help adolescents and/or adults to locate what they are looking for is difficult to anticipate, and further experiments must be done to substantiate these claims, for example, with texts or webpages.

Another limitation of this work is that this study evaluated the impact of the semantic induction task in comparison with that of a perceptual task, and not with a situation where no induction task was performed. Hence, no firm conclusion can be reached on whether the impact of the semantic task would be as important in comparison with the typical situation where no induction task is performed. However, as stated above, whereas performing the semantic task potentiated the impact of semantic distractors as expected, performing the perceptual task *did not* increase the impact of orthographic distractors. This suggests that the impact of the perceptual task was rather minimal, and that performing the perceptual task might be quite comparable to performing no induction task at all.

Altogether, in accordance with the main hypothesis of this work, performing the semantic induction task increased the time needed to find the target word relative to the perceptual one. The induction task impacted both the processes involved in the rejection of distractor words and the "automatic" attention guidance processes that determine which words are gazed at in the search display. Hence, the present study demonstrates that Kiefer and Martens' attentional sensitization theory may be applied to more complex verbal tasks than simple lexical decision.

Authors' contributions NV, JB, CR, and J-FR conceived and designed the study and the experimental material. NV, JB, DD, and CR conducted the experiments and analyzed the data. DD and NV wrote the first draft of the manuscript. J-FR made substantial contributions to the interpretation of the data and wrote sections of the manuscript. All authors contributed to manuscript revision, and read and approved the submitted version.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Conflicts of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. At the time the experiment was conducted, full review and approval of the study by an ethics committee or an Institutional Review Board was not required according to institutional and national guidelines and regulations.

Consent to participate Informed consent was obtained from all individual participants included in the study and from their legal guardians.

Consent for publication Not applicable.

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