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Linguistic Gender and Spoken-Word Recognition in French

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Eye movements were monitored as French participants followed spoken instructions to use a computer mouse to click on one of four displayed pictures. Experiment 1 demonstrated that, in the absence of grammatical gender in the context preceding the referent name [e.g., *cliquez sur les boutons* (click on the$_{\text{(plural neut.)}}$ buttons$_{\text{(masc.)}}$)], participants fixated pictures with names sharing initial sounds with the target [e.g., *bouteilles* (bottles$_{\text{(fem.)}}$)] more than on pictures with phonologically unrelated names, replicating "cohort" effects previously found with this paradigm. When a gender-marked article immediately preceded the noun [e.g., *cliquez sur le bouton* (click on the$_{\text{(masc.)}}$ button)], the early activation of the gender-inconsistent cohort was completely eliminated (Experiment 2). This demonstrates that the set of candidates initially considered for recognition of the noun is constrained by the gender-marked article. Two alternative accounts of these results, one based on grammatical level of processing and the other based on form-based statistics, are discussed.

Key Words: spoken-word recognition; linguistic gender; French; eye tracking.

The present research focused on gender in spoken-word recognition in French. All French nouns are either feminine or masculine. A noun's gender is phonologically marked in a variety of ways, including the form of the article. Masculine nouns are preceded by the definite article *le,* and feminine nouns are preceded by *la.* The question we examined is how gender marking on a definite article influences the recognition of the subsequent noun in spoken-language comprehension.

While many of the details of how spoken words are represented and accessed remain controversial, it is well established that as a word unfolds, recognition takes place against a backdrop of partially activated alternatives that compete for recognition. The most activated alternatives are those that most closely match the input (e.g., Marslen-Wilson, 1987; Zwisterlood, 1989). Thus, as a French listener hears *bouton* (button), lexical representations of words with similar sounds, such as *bouteille* (bottle), will be activated along with the lexical representation of the word itself.

Marslen-Wilson and colleagues (Marslen-Wilson, 1987, 1993; Marslen-Wilson & Welsh, 1978) first instantiated this idea in the Cohort model. According to this model, a "cohort" of lexical candidates is activated by the onset of a word. Activated candidates that become inconsistent with subsequent information drop out of the cohort. Recognition is achieved when only one candidate remains in the cohort or when the activation of one candidate is sufficiently greater than the other candidates. Subsequent models, such as TRACE (McClelland & Elman, 1986), Shortlist (Norris, 1994), and NAM (Luce & Pisoni, 1998), also assume that multiple candidates are activated, but differ in their assumptions about how the competitor set is defined. In these models, the candidate set is not defined strictly by the onset of a word; any part of the acoustic input can contribute to the activation of candidates (for further discussion, see Allopenna, Magnuson, & Tanenhaus, 1998; Connine, Blasko, & Titone, 1993; Marslen-Wilson & Zwitserlood, 1989).

As with other examples of temporary ambiguity, the ambiguity-resolution process for tem-

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porarily ambiguous words could, in principle, be influenced by correlated constraints from context. A distinction is often made between constraints that affect which lexical candidates are *initially* activated and constraints that do not affect initial activation but rather facilitate *selection* among the activated alternatives. For example, Zwitserlood (1989) conducted a detailed investigation of how semantic context influences activation for lexical cohort competitors. At various points in the presentation of the last word of a spoken sentence, the speech was truncated and a target word related to either the truncated actual word or a cohort competitor was visually presented for lexical decision. The sentential context preceding the truncated word was either neutral or semantically biased toward the actual word. When the acoustic information in the truncated word was ambiguous between the actual word itself and its cohort competitor, lexical decisions were facilitated for targets associated with either the actual word or its cohort competitor, regardless of contextual bias. However, facilitation to the target semantically related to the cohort persisted longer when the semantic context was neutral than when it was biased toward the actual word. On the basis of this time-course analysis, Zwisterlood concluded that the semantic contexts of the type she studied did not affect the activation of the initial candidate set, but rather affected the selection process among candidates.

In contrast to the voluminous literature on syntactic- and semantic-context effects on word recognition, the literature on morphosyntactic-context effects is sparse (e.g., Lukatela, Kostic, Feldman, & Turvey, 1983). The few studies that have focused specifically on gender have found strong effects. Colé and Segui (1994) found that lexical decisions to a noun are slowed when the noun is preceded by a gender-incongruent determiner or adjective (see also Jakubowicz & Faussart, 1998). Grosjean, Dommergues, Cornu, Guillelmon, and Besson (1994) showed that a gender-marked article preceding a gated (truncated) noun restricts the set of alternatives generated by participants; less acoustic information was needed for subjects to recognize the noun when a gender-marked article was present than when it was absent. Moreover, lexical decisions were faster on nouns when they were preceded by an article than when the article was omitted. Grosjean et al.'s results suggest that the presence of a gender-marked article can enhance the recognition of a noun. This conclusion was supported by Bates, Devescovi, Hernandez, and Pizzamiglio (1996) in Italian, using word-repetition, gender-monitoring, and grammaticality-judgment tasks. Performance in all three tasks was slower when the target noun was preceded by a gender-incongruent adjective and faster when preceded by a gender-congruent adjective (relative to a baseline condition using an adjective that was neutral with respect to gender). Although important, these studies do not directly investigate the role of gender information on the set of initially activated candidates. Specifically, they do not assess whether a candidate that shares the same onset as the target but mismatches the morphosyntactic context is initially activated.

In order to determine if a gender-marked article preceding a noun can influence which lexical candidates enter the competitor set, we examined the activation of a gender-inconsistent competitor that matched the initial sounds of the target word but mismatched the gender marking on the article. We assessed cohort-competitor activation by using the head-mounted eye-tracking paradigm, introduced by Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995) to study spoken-language processing in visual contexts and further developed by Allopenna et al. (1998) to explore spoken-word recognition (see also Cooper, 1974; Tanenhaus & Spivey-Knowlton, 1996). In those studies, participants followed spoken instructions to manipulate either real objects or pictures displayed on a computer screen while their eye movements were monitored using a lightweight camera mounted on a headband. Eye movements to objects in the workspace were closely time-locked to referring expressions in the unfolding speech stream, providing a sensitive and nondisruptive measure of spoken-language comprehension.

In the present research, French participants were presented with a computer display consist-

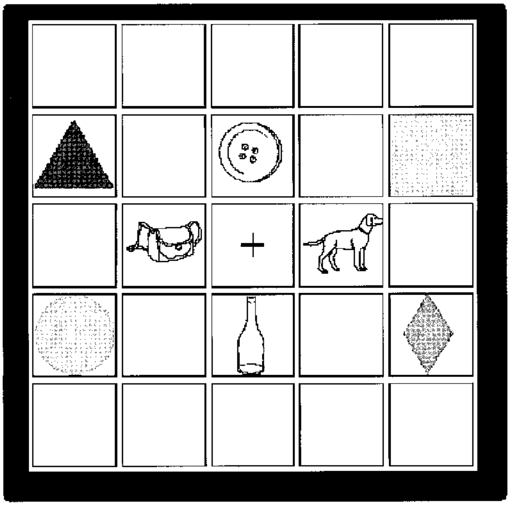

FIG. 1. Example of a visual display. Colors are omitted here. The triangle was blue; the circle, green; the square, orange; and the diamond, red.

ing of a centered fixation cross and four pictures and were given a spoken instruction to click on one of the pictures using the mouse [e.g., *cliquez sur le bouton* (click on the$_{\text{(masc.)}}$ button$_{\text{(masc.)}}$)]. The four pictures included the target (e.g., *bouton*), a cohort competitor (henceforth, cohort) [e.g., *bouteille* (bottle$_{\text{(fem.)}}$)], and two distractors (see Fig. 1). By recording the eye fixations generated during the presentation of the target word *bouton,* we were able to assess the activation of the gender-inconsistent cohort *bouteille.* This study investigated whether a gender-marked article affects the candidates initially considered for recognition of the following noun.

METHODOLOGICAL PRELIMINARIES

Before going into details specific to each experiment, we outline the characteristics of the methodology used here that were common to Experiments 1 and 2.

Participants

All participants were native speakers of French, recruited at the University of Rochester and in the Rochester area. Each participant took part in only one of the experiments presented here and was paid for his/her participation.

Materials

The French database "Brulex" (Content, Mousty, & Radeau, 1990) was used to select experimental items and to control for their frequency. The major constraint in selecting items was that the words had to be nouns referring to picturable objects. Pictures were selected from the Snodgrass and Vanderwart (1980) and Cycowicz, Friedman, Rothstein, and Snodgrass (1997) picture sets, as well as from children's picture dictionaries; all were black and white line drawings.[1]

The spoken instructions to be presented along with the pictures were recorded by a female native speaker of French (the first author) in a soundproof room, sampling at 22,050 Hz. Each instruction was then edited and some basic durations were measured.

Procedure

Participants were seated at a comfortable distance from the computer screen. Subjects' eye movements were monitored using an Applied Scientific Laboratories E4000 eye tracker. Two cameras mounted on a lightweight helmet provided the input to the tracker. The eye camera provided an infrared image of the eye. The center of the pupil and the first Purkinje image (corneal reflection) were tracked to determine the position of the eye relative to the head. A scene camera was aligned with the midline of the participant's head. A calibration procedure allowed software to superimpose crosshairs

[1] Ratings for French speakers have been established by Alario and Ferrand (1999) on the 400 line drawings from Snodgrass and Vanderwart (1980) and Cycowicz et al. (1997), and the pictures used here were mostly selected from this database. However, a few of the pictures had not been rated. In order to establish naming norms, we submitted the participants of our experiments to a naming task prior to the eye-tracking experiment. Each picture was individually presented on the computer screen and subjects were asked to type its name using the keyboard. We thus collected names for the 64 pictures of the critical 16 displays used to test cohort activation. A correct response was an answer that exactly corresponded to the intended name or the name followed by a modifying phrase. Thus, *grenouille* [frog] for the intended *crapaud* [toad] was not coded as a correct response, but *patin à glace* [ice-skate, lit. skate for ice] for *patin* [skate] was. The agreement between subjects' responses and the intended names was 91.8%.

showing the subject's point of gaze on a HI-8 videotape record of the scene camera's view. The scene camera sampled at a rate of 30 frames per second, and each frame was stamped with a time code. Auditory stimuli were played to the subject through headphones and simultaneously to the HI-8 VCR, providing an audio record of each trial. Two independent computers were used to present the visual and the auditory stimuli on each trial. The experimenter synchronized these two events by pressing both keyboards simultaneously.[2]

The structure of each trial was as follows: First, a 5 × 5 grid with a centered cross appeared on the screen, and subjects were instructed to look at the cross and to click on it. This allowed the experimenter to check that the calibration of the eye tracker was satisfactory. Then four line drawing pictures and four colored geometric shapes appeared on various cells of the grid (see Fig. 1). Participants were seated between 40 and 60 cm from the screen; each cell in the grid subtended 3 to 4° of visual angle, which is well within the resolution of the tracker (better than 1°). Approximately 500 ms after the pictures appeared, the spoken instruction started. The format of the instruction was constant across all trials: Subjects were first asked to click on one of the four pictures using the computer mouse [e.g., *cliquez sur le bouton* (click on the button)], and after a 500-ms delay to move the picture above or below one of the four geometric shapes [*mettez-le au-dessus/en-dessous du carré/ triangle/ losange/ cercle* (put it above/below the square/triangle/diamond/circle)]. Once this was accomplished, the next trial began. The geometric shape positions were fixed for all the trials. The position of each picture was randomized for each subject and each trial.

Subjects were free to scan the display before the instruction started, so at the onset of the article–noun phrase, they could be fixating any of the four objects or the cross. This procedure departed from the procedure used by Allopenna et al. (1998). In Allopenna et al., subjects were given approximately 2 s to inspect the pictures before they were instructed to fixate the cross until the next instruction began. The advantage of the Allopenna et al. procedure is that all fixations begin on the cross, eliminating baseline differences in fixations on pictures prior to the target word. However, a disadvantage is that it provides subjects with more time to inspect the pictures. Although subjects never reported naming the pictures to themselves in the Allopenna et al. procedure, we wanted to avoid any possibility that subjects would adopt a strategy in which they named the pictures to retrieve the gender of their names. Thus, we reduced the display time from 2000 to 500 ms. A disadvantage is that subjects tended to look at the pictures as soon as they were displayed. Thus, the proportions of fixations to each picture at noun onset was not zero, and sometimes there were baseline differences between conditions within an experiment. However, there were no systematic baseline differences between pictures across the experiments or among conditions.

Participants were given minimal information about the purpose of the experiment beforehand. They were told that the study focused on language comprehension and were asked to simply follow the spoken instructions to move the pictures.

Coding

The data were collected from the videotape records using an editing VCR with frame-by-frame controls and synchronized video and audio channels. Coders used the crosshairs generated by the eye tracker to establish where subjects were looking at each moment of the test trials. Fixations were coded on each trial from the onset of the target noun until the subject had moved the mouse cursor to the target picture. The onset of the target word on each trial was determined by monitoring the audio channel of the VCR frame by frame. Coders noted the onset of the instruction *cliquez sur. . .*; this time, plus the duration of the *cliquez sur le/la* instruction (independently measured with

[2] Note that timing measurements were made independently of the accuracy of this synchronization, since speech and eye movements were assessed directly from the video recording. Any variability in this synchronization resulted only in slight variance in the delay between the presentation of the pictures and the onset of the spoken instruction.

a speech-waveform editor), was identified as the onset of the target word.

To define a fixation, we adopted the following criteria. The subject's gaze had to remain on the object for more than one frame to be counted as a fixation. In the rare cases where it took more than one frame for a fixation to reach a new object (at most two frames), the traveling time was added to the fixation time on the previously fixated object. If blinking occurred, this time was added to the time of fixating the object fixated before blinking; note that most of the time, subjects would fixate the same point after blinking. In the rare cases where subjects fixated a point on the screen other than the cross or any picture, we coded it as a fixation to the cross.

Data Analysis

For each subject and each trial, we established which of the four pictures or the cross was fixated, at successive time frames, beginning with the onset of the target word, i.e., the noun. (A few analyses were conducted on fixations starting at article onset.) In order to compare the proportions of fixations to each picture, we defined a time window extending from 300 to 700 ms after noun onset, over which fixations to each picture or to the cross were summed (yielding a fixation proportion for each picture). This time window corresponds to the time window where Allopenna et al. (1998) observed more fixations to the cohort competitor than to an unrelated picture. It is estimated that the programming of an eye movement begins roughly 200 ms before it is launched (Matin, Shao, & Boff, 1993); eye movements triggered by acoustic information on the target word should thus be observed a few hundred milliseconds after target onset. Computations to assess cohort activations were thus conducted on the 300- to 700-ms window. In order to evaluate whether the cohort was fixated more than the distractors, we conducted planned comparisons between the fixation proportion to the cohort and the average fixation proportion to the distractors [one-tailed t tests, by subjects (t_1) and by items (t_2)].

In order to evaluate the time course of lexical activation as the speech unfolded, we computed the probability of fixating each picture over time and represented them graphically. These probabilities correspond to the proportion of fixations to each picture (target, cohort, distractor) for each subject over all trials, for each 33-ms video frame. Since there were two distractors, we averaged proportions of fixations for both distractors.

To evaluate if the initial baseline differences in fixating each picture could be attributed to noise, we conducted a one-way ANOVA on the looking times for the target, cohort, and distractors between 0 and 300 ms after target onset [by subjects (F_1) and by items (F_2)]. As shown below, there were no reliable differences in initial fixations between the cohort and the distractors—the only reliable difference between pictures was found in Experiment 1, where the target showed an advantage compared to the other pictures.

Although no significant differences on initial fixations between the cohort and the distractors were found, initial fixations to the cohort may have affected subsequent fixations. Indeed, if subjects happened to be looking at the cohort or at the target at the onset of the target word, they may have kept fixating it as the spoken input unfolded, consistent with the name of the picture they fixated. Thus, noise in subjects' initial fixation locations may have affected subsequent fixations. To remove this noise, we conducted contingent analyses by selecting the trials for which participants were fixating either the cross or one of the distractors. These analyses reduced any possible effects of initial baseline differences.

EXPERIMENT 1

Experiment 1 was conducted primarily to establish a baseline of cohort activation for the materials used in this study in the absence of gender marking. An obvious way to eliminate gender marking is to omit the definite article before the noun. However, omitting an article before a noun is uncommon in French. Therefore, we chose to use the plural definite article *les,* which is used before plural nouns, regardless of their gender [e.g., *les boutons* /lebutɔ̃/

(the buttons), *les bouteilles* /lebutɛj/ (the bottles)]. Based on prior work using the eye-tracking paradigm (e.g., Allopenna et al., 1998), we expected more fixations to a picture whose name shared the same initial phonemes as the target than to the picture of a phonologically unrelated distractor. This result would then let us study how gender information affects lexical competition.

In addition, Experiment 1 evaluated the possibility that, when gender information is available, listeners would use this gender information strategically as a consequence of having the set of alternatives visually available, in a way that would be impossible in normal comprehension. Upon hearing a gender-marked article, listeners might be able to strategically restrict their attention to those pictures whose name matched the gender of the article, resulting in few, if any, fixations to the gender-inconsistent cohort. Strategic selection of this type is possible in the eye-tracking paradigm because subjects are presented with a limited set of alternatives. However, this possibility seemed unlikely because gender is generally not predictable from the physical characteristics of objects. Moreover, native French speakers have the strong intuition that they cannot judge what gender would be used to describe a picture without first consciously retrieving its name, a strategy that subjects in the visual-world paradigm deny using (for suggestive evidence against a "naming" strategy, see Spivey & Marian, 1999). Nonetheless, it was important to evaluate the possibility that participants were able to extract the linguistic gender associated with each picture and subsequently restrict their attention to those that matched the gender marking on the article. If this were the case, the paradigm would be of limited usefulness for assessing the effects of gender on lexical access.

We presented participants with displays composed of four phonologically unrelated pictures. Two of the pictures (the competitors) were matched for lexical frequency and syllabic structure but were of different gender [e.g., *chaussette* (sock) and *balai* (broom)]. The other two pictures, matched for syllabic structure but of different gender, were alternatively (between subjects) target and distractor [e.g., *louche* (ladle) and *zèbre* (zebra)]. When the target was masculine (e.g., *zèbre*), the masculine competitor (e.g., *balai*) was consistent with the gender marking on the article preceding the target word, while the feminine competitor (e.g., *chaussette*) was not. Conversely, when the target was feminine (e.g., *louche*), the feminine competitor was consistent with the gender marking, while the masculine competitor was not. Thus, we compared the probability of fixating each of the competitors as a function of their consistency with the gender marking on the article preceding the target word. If participants were able to use gender marking to restrict their attention to the pictures that matched this information, the probability of fixating the gender-matching competitor should be higher than the probability of fixating the gender-mismatching competitor. Alternatively, if subjects cannot use gender to strategically select only gender-matching pictures, the proportion of fixations to each competitor should be equivalent.[3]

Method

Participants. Twelve native speakers of French participated in this experiment. All were born in France and had been living in the United States for 16 months on average (ranging from 2 weeks to 4 years).

Materials and Procedure

Test of cohort activation. Sixteen pairs of words that shared (at least) onset consonants but differed in gender were selected. Each pair was then paired with two phonologically unrelated distractors. The 16 pairs and their distractors are listed in Appendix A.[4] The members of each

[3] An advantage for fixating the gender-matching competitor could also result from lexical activation of gender-matching candidates by the gender information on the article, without calling for a strategy bias. Teasing these two alternatives apart would then be required.

[4] For half of the 16 target–cohort pairs, one distractor was of the same gender as the target and the other was of different gender. For the other half of the pairs, both distractors were of different gender than the target. This difference was not relevant here, since the gender of the target word was not marked on the article, but would be relevant in Experiment 2. As a result, for the items where both

pair often differed with respect to frequency of occurrence in the language. For example, the frequency of *ceinture* (belt) is 24.84 per million, whereas the frequency of *cintre* (coat hanger) is 0.31. Studies in our laboratory have shown that the probability of fixating a competitor that matches the acoustic information of the target word varies with its lexical frequency (Dahan, Magnuson, & Tanenhaus, submitted for publication). To control for word frequency in cohort competition, we created two different lists in which the function of each item (either target or distractor) was alternated. For instance, *ceinture* was the target and *cintre* its cohort competitor in one list, while *cintre* was the target and *ceinture* its cohort competitor in the other list. Six participants were randomly assigned to each list. For each list, three random orders were generated and an approximately equal number of subjects was assigned to each other.

To be consistent with the use of a plural definite article, each picture was "doubled" by duplicating it and reducing it in size, so that two identical objects appeared together.

The spoken instructions were recorded and edited, and some basic durations were measured. On average, "*cliquez sur*" (click on) was 543 ms long; the article, 118 ms; and the noun, 608 ms.

Test of use of gender information. To test the use of gender information, 16 word pairs of different gender matched for frequency were selected. All pictures had received high name agreement among French speakers, as reported in Alario and Ferrand (1999). (The name agreement was 95.6% on average, ranging from 71 to 100%.) Along with these competitors were two other words of different gender that alternatively (between subjects) played the role of target or distractor. This counterbalancing ensured that any preference for fixating pictures that matched the target gender could not be due to preferences for fixating specific pictures. The materials are presented in Appendix B. Two lists were created as a function of which pictures were target and distractor, and each subject was randomly assigned to one list. For each list, three random orders were generated and an approximately equal number of subjects were assigned to each order.

The spoken instructions were recorded; the mean duration of "*cliquez sur*" (click on) was 530 ms; the article, 121 ms; and the noun, 604 ms.

In addition to the 16 displays to test cohort activation in the absence of gender information, where all pictures were doubled, and the 16 displays to test the use of gender information on the article, where all pictures were single, 18 filler displays were constructed, composed of single and double pictures. Four filler trials were presented at the beginning of the session for participants to become accustomed to the task and procedure. The experimental session lasted approximately 12 min.

Results

Test of cohort activation. Over the 300- to 700-ms time window, the proportion of fixations to the target was 47.7%; to the cohort competitor, 21.2%; to each distractor, 12.1%; and to the cross, 7.0%. Planned comparisons (one-tailed t tests) between the fixations to the cohort competitor and the averaged distractors were conducted. The cohort competitor was fixated longer than the distractor ($t_1(11) = 2.72$, $p < .05$; $t_2(31) = 3.26$, $p < .005$). This result demonstrates that the cohort competitor was activated during the presentation of the target word as a result of its phonological similarity to the target.

Figure 2 displays the probability of fixating the target and the cohort and the averaged probability at fixating the distractors over time, from 0 to 1000 ms after noun onset. The graph shows that the probability of fixating the cohort began to diverge from the probability of fixating the distractor about 300 ms after noun onset and

distractors were of different gender than the target, the distractors varied depending on which item of the target–cohort pair was the target. For instance, for the pair *serpent*–*serrure* (snake–keyhole), when *serpent*$_{\text{(masc.)}}$ was the target (e.g., list 1), the distractors were *poire* (pear) and *tasse* (cup), both of feminine gender, while when *serrure*$_{\text{(fem.)}}$ was the target (e.g., list 2), *ballon* (balloon) and *piano* (piano), both masculine words, were distractors. In order to keep the set of pictures constant from one list to the other, the same distractors were used, but for different target–cohort pairs.

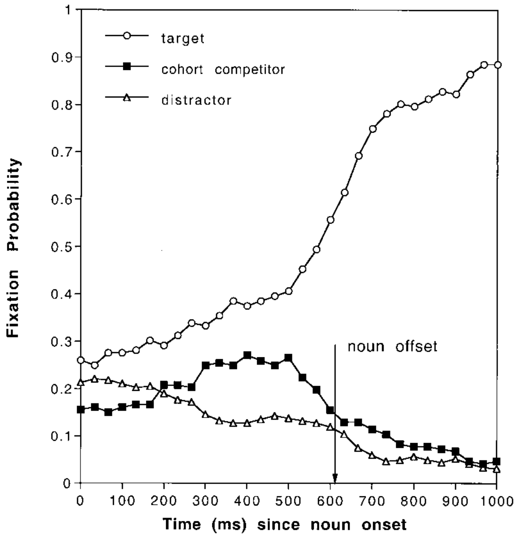

FIG. 2. Experiment 1: Fixation probabilities over time for the target, the cohort competitor, and the averaged distractors on the "cohort" trials.

remained higher until shortly after 700 ms. Comparisons on fixations over a 300- to 500-ms window and a 500- to 700-ms window confirmed these observations (on the 300- to 500-ms window, $t_1(11) = 2.58$, $p < .05$; $t_2(31) = 3.61$, $p < .001$; on the 500- to 700-ms window, $t_1(11) = 2.08$, $p < .05$; $t_2(31) = 1.88$, $p < .05$). To examine fixation differences before the 300- to 700-ms window, an ANOVA conducted on the fixations to the target, the cohort competitor, and the distractors over the first 300 ms after target onset indicated that the fixation proportions differed ($F_1(2, 22) = 7.0$, $p < .01$, $MSE = .0053$; $F_2(2, 62) = 4.61$, $p < .05$, $MSE = .0243$). Newman–Keuls tests indicated that the proportions of fixations to the target were higher than those to the other pictures, but the fixations to the cohort did not differ from those to the distractor. This early advantage for fixating the target must be attributed to noise—given the rather small number of observations—and not to a bias for the referent pictures, since each item of the target–cohort pairs was alternatively used as the referent.

We also conducted a contingent analysis by selecting the trials on which participants were fixating either the cross or one of the distractors at the onset of the target noun (112 of the 192 trials, 58.3%). Figure 3 presents fixation probabilities for the target, the cohort, and the averaged distractors over time. If subjects initially fixating one distractor were equally likely to shift to the other distractor or to the cohort, fixations to the cohort would not be expected to rise above fixations to the distractors. However, as shown in Fig. 3, subjects initially fixating one distractor were more likely to shift to the cohort than to continue fixating a distractor. This contingent analysis demonstrates that the "cohort" effect seen in over the entire set of trials cannot be attributed to baseline differences in subjects' initial fixations. Fixations to the cohort were significantly higher than fixations to the distractors from 300 to several hundred milliseconds after target onset (from 300 to 500 ms, t_1 (11) = 2.02, $p < 0.5$, $t_2(31) = 2.74$, $p < .01$; from 500 to 700 ms, $t_1(11) = 2.43$, $p < .05$, $t_2(31) = 1.8$, $p < .05$). The probability of fixating the target did not differ significantly from the probability of fixating the cohort until 500 ms after target onset (from 300 to 500 ms, $t_1 < 1$, $t_2 < 1$; from 500 to 700 ms, $t_1(11) = 6.97$, $p < .01$, $t_2(31) = 5.08$, $p < .01$).

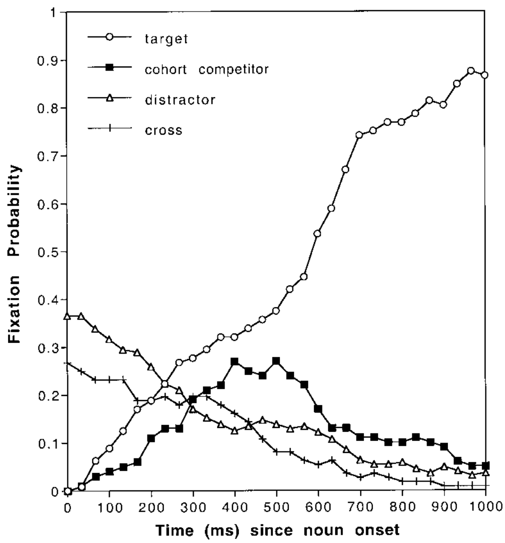

FIG. 3. Experiment 1: Fixation probabilities over time for the target, the cohort competitor, the averaged distractors, and the cross, restricted to the "cohort" trials that started on either distractor or on the cross at noun onset.

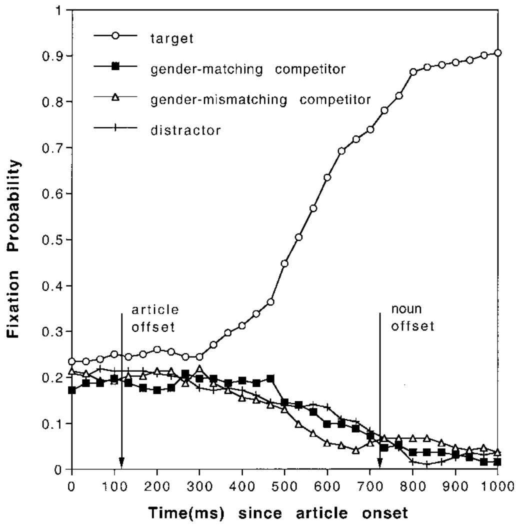

FIG. 4. Experiment 1: Fixation probabilities over time for the target, the gender-matching competitor, and the gender-mismatching competitor on the "gender" trials.

In sum, in the absence of gender marking on the article, cohort competitors received more fixations than phonologically unrelated distractors, indicating that the beginning of the nouns temporarily activated potentially matching lexical candidates.

Test of use of gender information. We computed proportions of fixations to the target, the gender-matching and the gender-mismatching competitors, the distractor, and the cross over the 300- to 700-ms window after *article* onset (where the gender information was coded). The percentages of looking time were 47.2% for the target, 14.3% for the gender-matching competitor, 14.9% for the gender-mismatching competitor, 11.9% for the distractor, and 11.8% for the cross. The fixation times did not differ between the two competitors (two-tailed matched-pairs t test, $t_1 < 1$, $t_2(31) = 1.37$, $p > .10$). Figure 4 presents the fixation probabilities for the target, both competitors, and the distractor. The probability of fixating either competitor did not differ significantly over time. Therefore, subjects did not use gender to restrict their fixations to pictures matching the gender of the spoken article.

Discussion

Experiment 1 established that in the absence of gender marking, the stimuli we selected showed evidence of a "cohort" competitor effect, as measured by eye movements. As the target word (e.g., /butɔ̃/) unfolded over time, listeners fixated the picture associated with the cohort competitor (e.g., *bouteilles*) more than they fixated pictures corresponding to phonologically unrelated distractors. We interpret these fixations as evidence that the lexical representation corresponding to the cohort competitor was briefly activated in the absence of gender marking preceding the target word. In addition, as expected, gender information carried by the article was not sufficient to restrict attention to pictures with gender-matching names, presumably because the pictures did not contain perceptual features onto which gender could be matched.

This combination of results sets the stage for using cohort effects to diagnose how gender information carried by a definite article affects lexical access for a subsequent noun. In the absence of gender marking, we know that cohort effects are obtained for this set of stimuli. We also know that gender marking *by itself* is not sufficient to restrict attention to pictures with gender-matching names. Thus, elimination of a cohort effect for a phonologically related competitor in the presence of mismatching gender information would be due to the effects of gender on lexical access and not a strategy due to using a restricted set of pictures.

EXPERIMENT 2

Experiment 2 tested whether the presence of a gender-marked article can prevent the early activation of nouns inconsistent with that gender. The inconsistency of the gender marking would certainly be expected to have an impact on the activation of a gender-inconsistent cohort at some time. Of interest is *when* the elimination of the cohort from the candidate set occurs. One possible scenario gives gender information the role of "filter," similar to what Zwitserlood (1989) established for sentential–semantic context: The initial competitor set is established solely on the basis of acoustic information from the target word. According to this scenario, early in the target word /butɔ̃/, all the candidates that are consistent with the acoustic information are activated, including the cohort *bouteille*. These candidates are then evaluated with regard to their contextual fit, that is, whether their gender fits with the gender-marked article. The cohort *bouteille* would then drop out of the candidate set. Alternatively, gender information might *block* the initial activation of a gender-inconsistent cohort; a cohort like *bouteille* would then never get activated, despite its phonological similarity with the target word /butɔ̃/. Experiment 2 distinguishes these possibilities by assessing the initial activation of gender-inconsistent cohort competitors.

Method

Participants. Twelve native speakers of French participated. All were born in France. Ten had been living in the United States for 14 months on average (ranging from 4 months to 5 years); 2 additional participants lived in France and were visiting relatives.

Materials. The same 16 target–cohort pairs of words used in Experiment 1 were used in Experiment 2, associated with the same distractors. By contrast with Experiment 1, the gender of these distractors mattered, because the article preceding the noun carried gender information. Experiment 1 showed that, for phonologically unrelated words, subjects did not look at the picture that matched the gender marking on the article more than the picture that did not, indicating that they did not use this gender marking to restrict the set of possible referents. Nevertheless, we varied the distractors' gender to prevent subjects from developing potential strategies. Distractors could either match or mismatch this gender marking. For half of the pairs, the distractors were both of a different gender than the target, whereas for the other half, one distractor was of the same gender as the target, while the other distractor was of different gender.

In addition to these 16 experimental trials, 24 filler trials were constructed to reduce the proportion of trials in which two items starting with similar sounds were presented simultaneously. In order to prevent subjects from developing expectations that pictures with phonologically similar names were likely to be targets, 7 of the filler trials contained two distractors that started with similar sounds. Four filler trials were presented at the beginning of the session to familiarize subjects with the task and procedure. As in Experiment 1, two lists were constructed in which each member of the target–cohort pair was alternatively the target and the cohort competitor. Subjects were randomly assigned to each list. For each list, five random orders were created. Approximately the same number of subjects were assigned to each order. The session lasted about 10 min.

The 64 pictures used for the 16 experimental trials were identical to those used in Experiment 1, except that only a single item was presented in each picture.

The mean duration of "*cliquez sur*" in the spoken instructions was 461 ms; the article, 123 ms; and the noun, 554 ms.

Results

For two subjects, a few trials were missing because of technical failure (one for one subject, seven for the other subject). In order to give these subjects' data the same weight as the other subjects' in computations, fixation values for these missing trials were estimated by using the subjects' average proportions over the remaining trials.

Over the 300- to 700-ms time window, the proportion of fixations to the target was 57.5%; to the cohort competitor, 14.1%; to each distractor, 12.1%; and to the cross, 4.2%. Planned comparisons conducted on the fixation difference between the cohort competitor and the averaged distractor revealed no significant difference ($t_1 < 1$, $t_2 < 1$). This suggests that, despite its phonological similarity with the target word, the cohort was not activated when the target word was preceded by a gender-marked article.

Figure 5 displays the probability of fixating the target, the cohort, and each distractor over time, from 0 to 1000 ms after noun onset. It confirms that the probabilities of fixating the

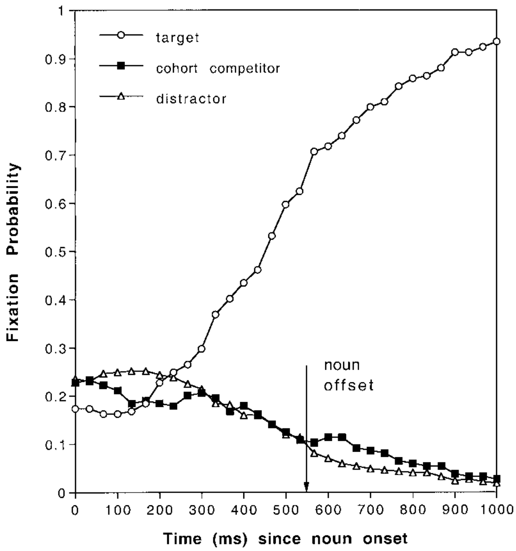

FIG. 5. Experiment 2: Fixation probabilities over time for the target, the cohort competitor, and the averaged distractors.

cohort and the distractor remained similar over time (from 300 to 500 ms, $t_1 < 1$, $t_2 < 1$; from 500 to 700 ms, $t_1(11) = 1.61$, $p > .05$, $t_2(31) = 1.19$, $p > .10$).

An ANOVA conducted on the fixations to the target, the cohort competitor, and the distractors over the first 300 ms after noun onset indicated no significant differences ($F_1 < 1$, $F_2 < 1$).

As in Experiment 1, we conducted a contingent analysis by selecting the trials for which participants fixated either the cross or one of the distractors at the onset of the target word (110 of 184 trials, 59.8%). Figure 6 presents fixation probabilities for the target, the cohort, the averaged distractor, and the cross. The probabilities of fixating the cohort competitor and the distractors merged around 300 ms after noun onset and progressively decreased as the probability of fixating the target increased. Planned comparisons revealed that the fixations to the cohort competitor never significantly exceeded those to the distractors within any time windows (all t_1 and $t_2 < 1$). This confirms that the probability of fixating the cohort competitor did not differ from the probability of fixating the distractors, regardless of which picture participants were fixating at the onset of the noun.

We also tested the hypothesis that the gender information on the article was sufficient to allow subjects to restrict their attention to pictures with names that matched the gender of the article by analyzing the fixations on each picture in a time window between 200 and 333 ms after *article* onset. This window was selected because it corresponded to when eye movements could be programmed in response to the gender information on the article alone prior to observing effects from the target word. We compared the fixations to the pictures that matched the gender information, including targets and distractors, with the fixations to the distractors and cohorts that mismatched the gender. Fixation proportions were computed and then averaged over the number of pictures involved in each condition. Over this time window, the gender-matching pictures were fixated 22.9% of the time, compared to 21.9% for the gender-mismatching pictures. This difference was not significant (two-tailed matched-pairs t test, $t < 1$). Moreover, the proportions of fixations to each type of picture did not significantly differ at any time frame over this window. This result is consistent with the results of Experiment 1 and

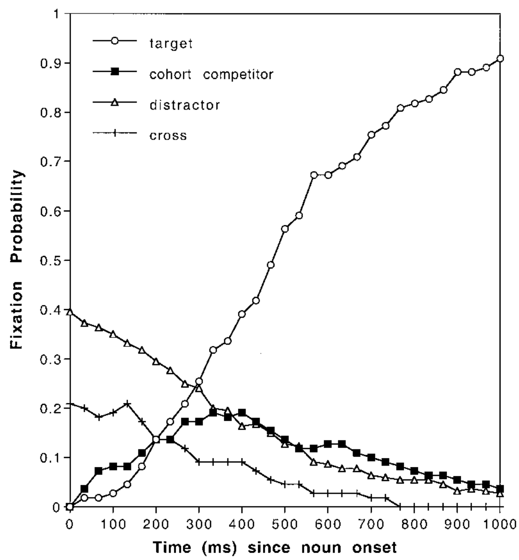

FIG. 6. Experiment 2: Fixation probabilities over time for the target, the cohort competitor, the averaged distractors, and the cross, restricted to the trials that started on either distractor or on the cross at noun onset.

indicates that subjects did not fixate one picture over another solely on the basis of whether its name matched the gender of the article.

Discussion

Experiment 2 provided clear evidence that when a gender-marked definite article preceded a noun, initial activation of a gender-mismatching cohort competitor was eliminated. In contrast with Experiment 1, fixations during the target word showed that the cohort was not fixated more than a phonologically unrelated distractor. This suggests that the cohort was not activated, despite its phonological similarity with the initial sounds of the target word. Thus, the language processing system exploits the contingency between the article and the noun in word recognition.

Additional support for this conclusion is provided by directly comparing the proportion of fixations to the target and the cohort between Experiments 1 and 2 over the 300- to 700-ms window. We analyzed both the fixations to the target and to the cohort competitor, because each one reflects a slightly different aspect of lexical processing. The fixations to the target provide information on accessing the lexical representations of the target, assuming that participants direct their attention toward the target picture once they have accumulated evidence that it is the referent picture (see Allopenna et al., 1998, for an implementation and test of this "linking" hypothesis). The fixations to the cohort provide information about activation of the competitors. As indicated earlier, the proportion of fixations to the target was 47.8% in Experiment 1 and 57.5% in Experiment 2; the proportion of fixations to the cohort was 21.2% in Experiment 1 and 14.1% for Experiment 2. A two-way ANOVA (Type of Picture—target or cohort—$\times$ Experiment) showed an effect of type of picture ($F_1(1,22) = 169.1$, $p < .001$; $F_2(1,31) = 127.9$, $p < .001$) and no effect of experiment ($F_1 < 1$; $F_2 < 1$). Importantly, the interaction between the type of picture and the experiment was significant ($F_1(1,22) = 9.98$, $p < .01$; $F_2(1,31) = 12.3$, $p < .001$). This indicates that over the 300- to 700-ms window, participants spent more time fixating the target in Experiment 2 than in Experiment 1 and spent less time fixating the cohort in Experiment 2 than in Experiment 1. The findings suggest faster lexical access and reduced cohort competition when the target was preceded by a gender-marked article.

GENERAL DISCUSSION

This study explored the use of morphological context in spoken-word recognition. In particular, it focused on whether French listeners use gender-marked information preceding a noun to constrain the set of activated lexical candidates to those that match this gender information. In order to assess the activation of gender-inconsistent words, we presented French subjects with a four-picture display and spoken instructions asking subjects to click on one of the pictures (e.g., the picture of a button, *bouton,* which is a masculine noun). Presented with the target picture was a "cohort" picture whose name shared the initial sounds of the target word but which was of different gender (e.g., the picture of a bottle, *bouteille,* a feminine noun) and two distractor pictures whose names were not phonologically similar to the target or cohort words. Eye movements to pictures were interpreted as evidence for the activation of the words corresponding to those pictures. Thus, greater fixation to the cohort picture than to the distractors as the target word unfolded over time indicated temporary activation of the gender-mismatching cohort competitor. Cohort activation was found when the target word was preceded by a gender-neutral article, *les* (Experiment 1); however, no cohort activation was found when a gender-marked article immediately preceded the target word (Experiment 2).

These results establish that the initial set of lexical candidates can be constrained by the preceding context: While cohort activation was found when the context contained no gender information, no such activation was observed when a gender-marked article immediately preceded the target word. To understand how the gender-marked article influences spoken-word recognition, it is important to distinguish among possible notional, grammatical, and form-based effects. First, activation of the article could activate the *notional* concept of masculine or feminine, thus biasing lexical concepts of gender-consistent nouns. However, this seems highly unlikely, given the absence of clear conceptual and perceptual correlates of gender in French. Some entities have names that are clearly masculine or feminine by virtue of their inherent gender, such as nouns used to refer to males and females, while other nouns tend to be masculine or feminine by virtue of shape (for example, round objects tend to have names with feminine gender, e.g., Bem, 1981). However, for most entities, gender cannot be predicted from either the physical properties or the function of the referent, such as its shape or size.

A second possibility is that listeners use the *grammatical* gender marked on the article to restrict the competitor set to words that are consistent with this grammatical gender. This constraint is a product of the grammatical structure of the language. In a noun phrase, the head noun, the article, and any possible adjectives must agree in gender. This dependency could be stated in terms of the probability for a word to appear, given the grammatical gender of the context preceding it, and possibly partial information from the target word itself—for example, the probability of the word *bouton* in the context of the acoustic information /bu/ preceded by masculine gender. This constraint could be instantiated by priming all the nouns consistent with the gender coded on the article and/or inhibiting the others. When the first sounds of the target word arrive, words that are consistent with the gender marking have been primed, and competitors that are inconsistent with the gender marking, such as the cohort competitor, have been inhibited and therefore will not become activated despite their similarity to the target-word form. On this account, one would expect to see more fixations to gender-matching pictures than to gender-mismatching pictures, since the words associated to gender-matching pictures would have been primed. However, neither Experiment 1 or Experiment 2 showed any evidence of more looks to gender-matching distractors than gender-mismatching distractors. Nevertheless, we cannot exclude the possibility that the priming occurs but is too weak to be observable in the absence of bottom-up information consistent with a gender-matching lexical candidate. Alternatively, the effect of grammatical gender might be expressed as conditional probabilities, in which the probability of a word occurring depends upon the grammatical gender present in the context (e.g., what is the probability of the word *bouton*, given the partial input /bu/ and the masculine gender information that precedes it). Crucially, these distributional regularities would be computed using grammatical categories (i.e., feminine or masculine). On this account, lexical access would make use of information from the grammatical level of language processing.

A third possibility is that the linguistic *forms* marking gender, rather than grammatical categories, influence access of the subsequent noun. Distributional regularities could be computed between the form of the preceding word (or sequence of phonemes) and the form of the following word: As the first sounds of the target word are heard following its gender-marked article (e.g., /ləbu/, le bou. . .), the probability of the target word being *bouton* in the context of *le* is high, whereas the probability of the target word being *bouteille* in this context is very low, based on the sound-based statistics of the language. Article–noun co-occurrence in French is very high: There is a strong tendency for nouns to occur with an accompanying determiner, and the definite article is used even in the cases where no determiner is semantically required (e.g., I like cheese, *j'aime le fromage*, Harris, 1990). Moreover, although adjectives can be inserted between determiners and nouns, they often occur after nouns. On this account, the processing system would keep track of sound-based contingencies and use these contingencies during word recognition.

The difference between form-based and grammar-based effects is subtle, but important. The grammar of French stipulates that the masculine article *le* precedes *bouton*, which is masculine. The grammar results in this statistical fact about /lə/ and *bouton*. But listeners' possible sensitivity to this fact in word recognition could reflect either sensitivity to the grammatical rule, defined in terms of the categories "masculine" and "feminine", or sensitivity to the co-occurrence of the forms /lə/ and /butɔ̃/ themselves.

These two accounts may have quite different consequences on the architecture of the spoken-word recognition system and on the processing taking place. The present study does not allow us to decide whether the grammatical gender carried by the article, or its high form-based co-occurrence with the target, constrained the competitor set by excluding the gender-inconsistent cohort competitor. In order to tease apart these alternatives, it is necessary to create contexts in which grammatical gender information precedes the noun, but the forms carrying the gender information and the target have a relatively low co-occurrence. This could be done by using lower frequency gender-marked articles, by interposing one or more words between the gender-marked definite article and the noun, or by using a lower frequency word, such as an adjective, to provide gender information. Research using this strategy is currently in progress in our laboratory.[5]

In most models of spoken-word recognition, lexical activation is primarily a function of the degree of match between the spoken word and stored lexical representations, modulated by characteristics of the word itself, such as its frequency. This study demonstrates that initial lexical activation can be constrained by speech external to the word itself. A full account of word recognition in continuous speech must thus refer to the context preceding the word.

[5] Our preliminary results support the form-based co-occurrence hypothesis. We presented French participants with the same picture displays, but the spoken instructions were varied: The grammatical gender information was carried by an adjective, rather than by a definite article [e.g., *cliquez sur l'astucieux bouton* (click on the$_{\text{(neut.)}}$ cleverly constructed$_{\text{(masc.)}}$ button$_{\text{(masc.)}}$]. The target word was thus immediately preceded by gender information, as in Experiment 2 of the present study; however, the adjective was chosen to have a much lower frequency of occurrence with the target in the language than the definite article. Cohort activation was found, suggesting that gender information coded on an adjacent adjective seems not have constrained lexical processing the same way as gender information coded on an adjacent definite article.

APPENDIX A: MATERIALS FOR "COHORT" TRIALS IN EXPERIMENTS 1 AND 2

Target–cohort pairs		Distractors	
vase* (vase)	vache* (cow)	livre (book)	pipe (pipe)
patin* (skate)	passoire (colander)	violon (violin)	fenêtre (window)
guidon* (handlebar)	guitare* (guitar)	verre (glass)	souris (mouse)
crapaud* (toad)	cravate (tie)	champignon (mushroom)	maison (house)
colonne* (column)	collier (necklace)	bougie (candle)	poisson (fish)
pelle (dustpan)	peigne (comb)	chaise (chair)	clou (nail)
poussette* (infant stroller)	poussin* (chick)	chemise (shirt)	sifflet (whistle)
couronne (crown)	couteau (knife)	chaussure (shoe)	lapin (rabbit)
serpent* (snake)	serrure* (keyhole)	poire/ballon* (pear/balloon)	tasse/piano (cup/piano)
râteau (rake)	raquette (racket)	banane/canard (banana/duck)	fourmi/cochon (ant/pig)
radis* (radish)	radio* (radio)	cloche/bus (bell/bus)	bague/nez (ring/nose)
bouton (button)	bouteille (bottle)	salière/chien (salt shaker/dog)	valise/sac (suitcase/pocketbook)
ceinture* (belt)	cintre (hanger)	ballon*/poire (balloon/pear)	piano/tasse (piano/cup)
sandale* (sandal)	sandwich (sandwich)	bus/banane (bus/banana)	nez/fourmi (nose/ant)
tirelire* (piggy bank)	tiroir* (drawer)	chien/salière (dog/salt shaker)	sac/valise (pocketbook/suitcase)
selle (saddle)	seau* (bucket)	canard/cloche (duck/bell)	cochon/bague (pig/ring)

Note. An asterisk indicates the pictures that were not from the Snodgrass and Vanderwart (1980) or Cycowicz, Friedman, Rothstein, and Snodgrass (1997) picture sets.

APPENDIX B: MATERIALS FOR "GENDER" TRIALS OF EXPERIMENT 1

Competitors		Target/distractor	
Masculine	Feminine	Masculine	Feminine
doigt (167) (finger)	fleur (164) (flower)	saxophone (saxophone)	télévision (TV)
cheval (135) (horse)	voiture (118) (car)	banc* (bench)	boîte (box)
bureau (105) (desk)	montagne (101) (mountain)	tigre (tiger)	roue (wheel)
chat (43.26) (cat)	corde (42.75) (rope)	requin (shark)	méduse (jellyfish)
puits (23.73) (well)	jupe (22.07) (skirt)	gâteau (cake)	casserole (pot)
noeud (23.27) (bow)	poêle (19.18) (pan)	gorille (gorilla)	girafe (giraffe)
coq (18.42) (rooster)	cage (19.86) (birdcage)	ballon (ball)	balance (scale)
lion (17.91) (lion)	flèche (17.91) (arrow)	bocal (jar)	baleine (whale)
fouet (15.4) (whip)	chèvre (15.23) (goat)	scorpion (scorpion)	toupie (top)
marteau (11.69) (hammer)	trompette (11.91) (trumpet)	cygne (swan)	brosse (brush)
tonneau (9.91) (barrel)	fusée (9.87) (rocket)	microscope (microscope)	chauve-souris (bat)
balai (7.23) (broom)	chaussette (7.91) (sock)	zèbre (zebra)	louche (ladle)
citron (5.02) (lemon)	tortue (5.57) (turtle)	robinet (faucet)	pyramide (pyramid)
cerf (3.82) (deer)	scie (4.21) (saw)	vélo (bicycle)	grenouille (frog)
dauphin (3.7) (dolphin)	tomate (3.44) (tomato)	cerf-volant (kite)	coccinelle (ladybug)
cactus (1.65) (cactus)	moto (1.57) (motorcycle)	nid (nest)	veste (jacket)

Note. An asterisk indicates the pictures that were not from the Snodgrass and Vanderwart (1980) or Cycowicz et al. (1997) picture sets. Lexical frequency (number of occurrences per million) for each competitor is indicated in parentheses (taken from Content et al., 1990).

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