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ARTICLE INFO

Keywords:
Typography
Eye movement
Optimal viewing position
Lexical decision

ABSTRACT

Two eye-movement experiments were conducted to examine the effects of font type on the recognition of words presented in central vision, using a variable-viewing-position technique. Two main questions were addressed: (1) Is the optimal viewing position (OVP) for word recognition modulated by font type? (2) Is the cursive font more appropriate than the printed font in word recognition in children who exclusively write using a cursive script? In order to disentangle the role of perceptual difficulty associated with the cursive font and the impact of writing habits, we tested French adults (Experiment 1) and second-grade French children, the latter having exclusively learned to write in cursive (Experiment 2). Results revealed that the printed font is more appropriate than the cursive for recognizing words in both adults and children: adults were slightly less accurate in cursive than in printed stimuli recognition and children were slower to identify cursive stimuli than printed stimuli. Eye-movement measures also revealed that the OVP curves were flattened in cursive font in both adults and children. We concluded that the perceptual difficulty of the cursive font degrades word recognition by impacting the OVP stability.

1. Introduction

Processing written language naturally requires the development of a number of strictly linguistic skills. However, reading also requires a visual analysis that enables the precise decoding of written words. Limitations of the human visual system strongly constrain the accuracy and the speed with which words can be recognized. Many factors, such as word length (e.g., Rayner & McConkie, 1976) or word frequency (see Rayner, 1998, for a review), are known to affect how quickly words are processed. Another factor known to have a major impact on word reading efficiency in adults is the position of eye fixation in the word (when there is only one fixation). Experiments manipulating eye fixation location in single word reading experiments have revealed an "optimal viewing position" (OVP), located slightly left of center, at which word identification is easiest (O'Regan & Jacobs, 1992; O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984; Vitu, O'Regan, & Mittau, 1990). This position is optimal for word recognition because it lowers the probability of refixation and thus shortens the recognition time, with a delay of 20 msec for each letter situated away from this position (O'Regan et al., 1984). These results suggest that readers might direct their eyes toward the centers of words because this is the OVP, i.e. the position from where words can be identified most rapidly (O'Regan, 1990, 1992; O'Regan & Lévy-Schoen, 1987).

The OVP effect, investigated in a number of studies, indicates how the initial horizontal placement of the eyes in a word constrains its identification and the subsequent eye movement pattern (for reviews, see Brysbaert & Nazir, 2005; Rayner, 1998). The OVP curve has two main characteristics: the location of its minimum (or maximum according to the studied variable) and its slope (i.e. how performance increases or decreases as the eyes fixate away from the optimal location). The classical finding is that various measures of word reading ability show best performance with fixations slightly left of the center of words (for languages that are read from left-to-right), and performance dropping with fixations further away from the OVP, following an asymmetric inverted J-shaped function (e.g., O'Regan & Jacobs, 1992; O'Regan et al., 1984; see Brysbaert & Nazir, 2005, for a review). Several developmental studies showed that an adult-like pattern is attained very rapidly while learning to read, even at the end of the first year (Aghababian & Nazir, 2000; Ducrot, Pynte, Ghio, & Lété, 2013); suggesting that beginning readers extract visual information from words in much the same way as proficient readers do.

It is generally agreed that the OVP effect results mainly from the

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https://doi.org/10.1016/j.actpsy.2018.06.003
Received 27 March 2017; Received in revised form 8 June 2018; Accepted 8 June 2018

rapid drop-off of visual acuity (and the strong increase of crowding) with retinal eccentricity, with letters viewed centrally benefiting from higher resolution than those further from fixation. The off-center location of the OVP can be explained by different, and complementary, factors. The first factor concerns the functional asymmetry related to speech lateralization in the left hemisphere for the vast majority of readers (e.g., Brysbaert, 1994; Van der Haegen, Cai, Stevens, & Brysbaert, 2013). Van der Haegen et al. (2013) observed that the left hemisphere dominant readers were faster at word recognition while fixating more toward the left of a word, as compared with right hemisphere dominants. Furthermore, it has been shown that the visibility of the word's component letters, as well as the information carried by these component letters, may contribute to the asymmetry in the OVP (Clark & O'Regan, 1999; Legge, Ahn, Klitz, & Luebker, 1997; Stevens & Grainger, 2003). Given that the most informative letter of words in languages such as English and French is the first letter (Dandurand, Grainger, Duñabeitia, & Granier, 2011), it follows that fixations somewhere between the beginning and the center of a word will optimize the total amount of information available from all letters in the word (Stevens & Grainger, 2003). Thus, the OVP emerges at the location that maximizes letter perceptibility and minimizes lexical ambiguity. Note that reading habits, and more precisely perceptual learning, may also contribute to determining both the shape and the asymmetry of OVP curves (Nazir, Ben-Boutayab, Decoppet, Deutsch, & Frost, 2004). According to the perceptual learning account, the visual training associated with the regularity of reading eye movements improves word recognition within a restricted horizontal region close to the fovea and mostly within the regions of the retina that fall on the side of the reading direction (Dehaene, Cohen, Sigman, & Vinckier, 2005). According to Nazir (2000), the OVP function would be a consequence of the distribution of initial landing positions of the eyes in reading with frequently fixated positions becoming optimal for word recognition (Nazir, Jacobs, & O'Regan, 1998; Nazir et al., 2004, but for a different point of view, see Ducrot et al., 2013; Paterson, Almabruk, McGowan, White, & Jordan, 2015).[1]

While the mechanisms underlying the OVP effect have largely been studied, there is an ongoing debate about the contribution to the OVP phenomenon of low-level visual factors. In line with the hypothesis of a predominant role of visual constraints, it has been demonstrated that the shape of OVP curves varies with the visual characteristics of the stimuli (e.g., Nazir et al., 1998; Nazir, Heller, & Sussmann, 1992). However, the OVP effect has always been studied using printed fonts and no studies have been conducted to measure the OVP effect with words displayed in cursive. Whether the OVP effect generalizes to words displayed in cursive font is a central question for visual word recognition. This manipulation could provide further evidence for an important role of visual constraints in determining the shape of the OVP phenomenon. To provide further insight on this issue, and also in an attempt to better understand the origin of the OVP phenomenon, this study tested whether words displayed in a cursive font exhibit the same VP function as words displayed in a printed font.

Many studies have been conducted to evaluate the effects of font type on word recognition and the vast majority of them compared printed and handwritten words (e.g., Barnhart & Goldinger, 2010; Gil-López, Perea, Moret-Tatay, & Carreiras, 2011; Manso De Zuñiga, Humphreys, & Evett, 1991; Perea, Gil-López, Beléndez, & Carreiras, 2016). A consensus emerges about the cost associated with the processing of handwritten words: the high intra- and inter-individual variability characterizing handwritten words produces noise that requires more "top-down" processing (Barnhart & Goldinger, 2010; Gil-López et al., 2011; Manso De Zuñiga et al., 1991). Reading handwritten words thus represents a great challenge in comparison with the reading of printed words that do not exhibit such variability: readers have to successfully cope with the absence of physical delimitations between letters when they are chunked with practice (Ramkumar et al., 2016), with the ambiguity of elementary strokes and loops, and with the considerable intra-and inter-subject variability in the shape of the letters. More precisely, two important difficulties in reading handwritten words were reported by Lorette (1999): polysemy and segmentation. Polysemy emerges from the variability in handwritten letters that may generate ambiguity, for example when two different characters have similar forms in handwriting (e.g., e and c) or when a same letter can be written in two different writing styles (e.g., s and s). The second difficulty concerns the segmentation of handwritten words that requires more top-down processing, for example when two characters are linked in such a way that they can be confounded with a single character (e.g., ev and w – 'ev' and 'w'). In line with this, it has also been reported that the absence of spaces within the stimulus has a negative influence on saccade computation since it reduces the probability that the eyes reach the PVL in comparison with stimuli containing spaces (Ducrot & Pynte, 2002). Finally, beyond the segmentation difficulties when letters are linked completely, the spacing variability between the handwritten characters produces more lateral masking leading to a crowding effect that can disrupt perceptual identification (e.g., Gori & Facoetti, 2015) and slow down reading (Pelli et al., 2007).

Although the majority of these results comes from the comparison between printed and handwritten words that can be composed of either cursive or printed letters (or both), most of the arguments put forward against handwritten fonts (absence of delimitation between characters, segmentation and polysemy difficulties) can also be applied to the standard cursive font (e.g., Hellige & Adamson, 2007). It is well-known that skilled readers develop a singular form of visual expertise that allows them to process words with remarkable efficiency, most likely because they are extensively trained and exposed to reading (Nazir et al., 2004; Nazir, 2000; but see Dehaene et al., 2005). It has also been shown that skilled readers are so used to processing words in a printed font, that reading performance immediately deteriorates when words are disrupted, e.g., by alternating cAsE (Mayall, Humphreys, & Olson, 1997), by spacing letters or rotating words (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008), or by using unfamiliar and less legible fonts (Slattery & Rayner, 2010). Together, these studies support the idea that cursive words are associated with a reading cost.

Interestingly, the hypothesis that cursive words could in fact be advantageous for reading can also be justified. For example, it has been argued that the cursive font may reduce letter confusion and improve the recognition of an isolated word. Word reading is mediated by letter processing within the limits imposed by the visual acuity and crowding (e.g., Grainger, Dufau, & Ziegler, 2016; Grainger, Rey, & Dufau, 2008). When the letters in the text are less difficult to encode, reading speeds up as readers make less and shorter eye fixations (e.g., Rayner, 1998). Letter identification may be facilitated in cursive font because it does not contain mirror letters, unlike printed font. Indeed, mirror letters such as 'b' - 'd', and 'p' - 'q' only appear in printed fonts and are known to be the most confusing letters for poor readers (Terepocki, Kruk, & Willows, 2002; Wolff & Melngailis, 1996).

Another argument that was made in favor of a cursive font is that writing related-knowledge is an important factor in the reading process. A large series of behavioral studies support the view that motor information encoded during the practice of handwriting plays a role in letter identification and gives rise to improved letter recognition (e.g., James & Gauthier, 2006; Longcamp, Zerbato-Poudou, & Velay, 2005). This hypothesis was corroborated by psychophysical studies showing that the way we visually perceive a letter is influenced by the rules we follow to write it (Tse & Cavanagh, 2000), and also by neuroimaging studies reporting activity within the writing network during reading

[1] Evidence of a dissociation between this optimal landing position, called Preferred Viewing Location (PVL), and OVP was also reported (Ducrot et al., 2013; Johnson & Starr, 2017; Paterson et al., 2015). Such dissociations between PVL and OVP provide further key evidence in favor of the hypothesis that the OVP is rather determined by how much information can be extracted from the written word when looked at from a particular angle, independently of how often that word has been read from that angle in the past.

(e.g. Longcamp, Anton, Roth, & Velay, 2003).

The aim of this study was to determine if the processing of a cursive font is associated with a cost or a benefit, in comparison with the processing of a printed font. To do this, we ran an experiment that aimed to elicit the impact of the font on skilled readers' word recognition. We compared two distinct fonts (cursive vs. printed) and used a variable-viewing-position technique, coupled to a lexical decision task. Because cursive and printed words differ in their geometrical structure (absence vs. presence of spaces between characters), their perceptual difficulty (polysemy or segmentation vs. mirror letters) and also in the motor information associated, we hypothesized that the lexical decision performance as well as the viewing position (VP) function should be modulated by the font. More precisely, assuming that the detection of space between characters is an automatic feature of the expert reading process, even very early stages of processing as assessed by a VP manipulation might prove sensitive to the font. Adult readers develop a singular form of visual expertise that allows them to process print with greater efficiency than cursive.

2. Experiment 1

2.1. Material and methods

2.1.1. Participants

Sixteen adults (between 20 and 30 years; 8 females) from Aix-Marseille University volunteered to participate. They were native speakers of French and had normal or corrected-to-normal vision; none suffered from any neurological, psychiatric, or emotional disorders. These adults were considered as expert readers, since all of them had a minimum of second-year university level. All protocols and procedures were in accordance with the 1964 declaration of Helsinki.

2.1.2. Material and stimuli

Eye-movement data were collected by a mobile infrared, head-mounted eye tracker (Eyelink 2, SR Research Ltd., Canada). The recording was based on infrared-light reflection from the pupil and cornea at a sampling rate of 250 Hz. Although participants read binocularly, only the right eye was tracked, at a spatial resolution of < 0.04°. A chin-and-forehead rest was used to minimize head movements. Prior to the experiment, the eye-tracker was calibrated using a 9-point calibration grid that extended over the entire computer screen. Before each trial, the calibration was checked by presenting a fixation point in the center of the screen. The eye tracker was interfaced with a Dell D-type docking station and a Dell Latitude D600 laptop computer.

A pool of 80 French words of five and six letters and 80 pseudowords composed of five and six letters were used. The words were selected from Manulex (Lété, Sprenger-Charolles, & Colé, 2004). 93% of the words were nouns, 4% were verbs, and 3% were adjectives. For the pseudowords, the orthographic regularity of all trigrams was taken into account in such a way that trigram frequencies were matched to the words (Content & Radeau, 1988). The stimuli are available as Supplementary material.

The stimuli were presented foveally, using a variable-viewing-position technique (see Fig. 1). Each stimulus was divided into five equally-wide zones (i.e., one letter wide for a five-letter stimulus and 1.2 letters wide for a six-letter stimulus). Stimuli were presented in such a way that participants initially fixated the center of each zone (hereafter called positions P1, P2, P3, P4, and P5). The different conditions were randomly interleaved in each block.

2.1.3. Task and procedure

All participants were tested individually. Participants were asked to perform a lexical decision task on a series of letter strings. At the beginning of each trial, they first had to fixate a cross displayed in the middle of the screen. After a delay of 500 ms, the participants saw the linguistic stimuli displayed on the screen in lowercase white letters on a black background. Once the stimuli appeared, the participants had to decide as quickly and accurately as possible whether or not the stimulus was a French word by pressing the corresponding button (blue button for "yes", red button for "no", see Fig. 1). The orientation of the button box was counterbalanced between participants in such a way that half of the participants had to identify the words with the non-dominant hand and vice versa. The entire experiment lasted approximately 20 min.

Two different fonts were used. Half of the stimuli were presented with the Cursive Standard font in 54-point and the other half with the Courier New font in 34-point. Different sizes were applied between the two fonts in order to make their size equal on the screen (corresponding to a width of 25 mm for five-letter stimuli and a height of 5 mm for x-height letters). A 14-inch color monitor, at a resolution of 1024 × 768 pixels, was used. Note that participants were seated 60 cm from the screen. At this distance, one letter subtended a visual angle of 0.48° and a stimulus of 5 letters covered 2.39°.

The presentation order between the two fonts was counterbalanced between participants and the association between the font and the linguistic stimuli was also counterbalanced between participants in such a way that the same stimuli were presented with the printed font for half of the participants and in cursive for the other half.

2.1.4. Data analysis

The two well-known lexical decision performance measures were computed: the percentage of correct responses and the lexical-decision time, computed for correct responses only. Furthermore, the eye-tracking data were analysed using customized software scripts written in C++ (Emaa software package: Ducrot, Lété, Descottes, Muneaux, & Ghio, 2006). The following eye-movement measures were computed: the initial-fixation duration (the duration of the first fixation within the word before making a saccade), the number of fixations, and the refixation position (the position of the second fixation within the word after a corrective saccade).

For all variables, except for the refixation position, analyses of variance (ANOVAs) were conducted, based on the participant (F_1) and item (F_2) mean performance, and using the following design: Lexicality (2 types of stimulus: words and pseudowords) × Font (2 modalities: cursive and printed) × Position (5 modalities: P1, P2, P3, P4, and P5). All significance thresholds were set to $p < 0.05$. Bonferroni's post hoc tests were applied when necessary (based on F_1). Concerning the refixation position, because participants did not systematically produce a corrective saccade, we have only reported their frequency-density distribution as a function of the Font type.

2.2. Results

Trials were excluded from the analysis when a blink occurred during stimulus presentation, fixations were shorter than 80 ms or longer than 1500 ms, the x-coordinate of the initial fixation was outside the cross area (illustrated by the dotted line rectangle in Fig. 1), the x-coordinate of the second fixation was outside the stimuli area or participants took > 1500 ms before pressing the button. This resulted in a rejection of 4.2% of the trials. The data exclusion was independent of the experimental conditions.

2.2.1. Lexical decision performance

2.2.1.1. Percentage of correct responses. The ANOVA revealed a main effect of Font only on the percentage of correct responses ($F_1(1, 15) = 5.47$, $p < 0.05$, $\eta_p^2 = 0.27$; $F_2(1, 158) = 4.48$, $p < 0.05$, $\eta_p^2 = 0.03$): The percentage of correct responses was slightly lower for cursive stimuli than for printed (96.15% and 97.8%; see Fig. 2).

2.2.1.2. Response time. As can be seen in Fig. 3, the ANOVA revealed a main effect of Lexicality ($F_1(1, 15) = 43.54$, $p < 0.001$, $\eta_p^2 = 0.74$;

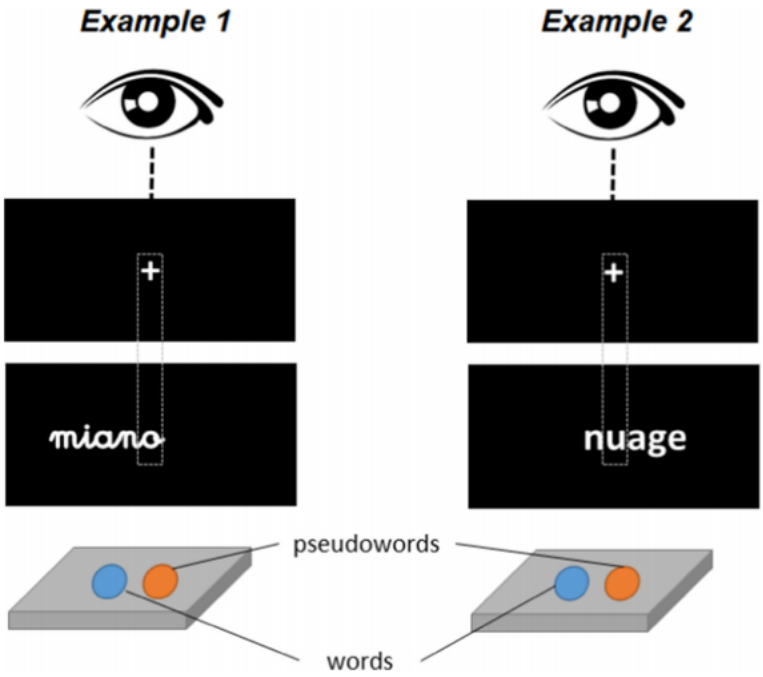

Fig. 1. Procedure: two examples of trials. In example 1, the pseudoword "miano" was presented with a Standard Cursive font and at position 5 (P5). The participant had to press the red button. In example 2, the French word "nuage" (cloud) was presented with a Courier New font and at position 2 (P2). The participant had to press the blue button. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

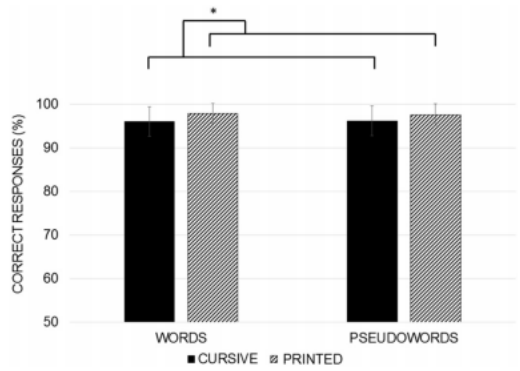

Fig. 2. Percentage of correct responses in the adults group as a function of Lexicality (words and pseudowords) and Font (cursive and printed). Error bars correspond to inter-participants SD. *$p < 0.05$; ***$p < 0.001$.

$F_2(1, 158) = 153.52$, $p < 0.001$, $\eta_p^2 = 0.49$) on the response time: The words were identified faster than the pseudowords (659 ms and 760 ms, respectively). This finding was expected in adults: the difference of time results from the delay used to verify that the pseudowords are not present in their lexical repertory and word identification was really easy for them because words were selected from the first-grade lemma lexicon of Manulex. The analysis also revealed a main effect of Position ($F_1(4, 60) = 13.50$, $p < 0.001$, $\eta_p^2 = 0.47$; $F_2(4, 632) = 11.45$, $p < 0.001$, $\eta_p^2 = 0.07$) on response time. Post-hoc analysis of the Position effect showed that the response time in P5 was longer than in P1-P2-P3 and that response time in P2 was shorter than in P4.

2.2.2. Eye-movement measures

2.2.2.1. Initial-fixation duration. The ANOVA revealed a main effect of Position ($F_1(4, 60) = 102.46$, $p < 0.001$, $\eta_p^2 = 0.87$; $F_2(4, 632) = 354.47$, $p < 0.001$, $\eta_p^2 = 0.69$). Post-hoc analysis confirmed that the initial-fixation duration was significantly different in each position ($p < 0.01$ for all comparisons except between P1 and P5 from F_1, $p = 0.91$), confirming the consistent relationship between the initial-fixation location and the initial-fixation duration, i.e. longest initial-fixation durations for initial fixations in the central region of the word corresponding to an inverted-OVP (IOVP) effect (Nuthmann, Engbert, & Kliegl, 2005; Vitu, McConkie, Kerr, & O'Regan, 2001). The Font by Position interaction was also significant ($F_1(4, 60) = 5.12$, $p < 0.01$, $\eta_p^2 = 0.25$; $F_2(4, 632) = 7.80$, $p < 0.001$, $\eta_p^2 = 0.05$). The post-hoc tests revealed that this interaction results from an opposite effect of Font between P2 and P3: the initial-fixation duration increases in P2 and decreases in P3 in the cursive font, compared to the printed font ($p < 0.01$ and $p < 0.05$, respectively). However, the comparison between each position revealed the same pattern of results in both fonts (see Fig. 4 for more details).

2.2.2.2. Number of fixations. The ANOVA revealed a main effect of Lexicality ($F_1(1, 15) = 17.69$, $p < 0.001$, $\eta_p^2 = 0.54$; $F_2(1, 158) = 27.20$, $p < 0.001$, $\eta_p^2 = 0.15$), such that words were identified with less fixations than pseudowords (2.1 and 2.3, respectively). The analysis also revealed a mean effect of Position ($F_1(4, 60) = 68.20$, $p < 0.001$, $\eta_p^2 = 0.82$; $F_2(4, 632) = 140.82$, $p < 0.001$, $\eta_p^2 = 0.47$). The post-hoc analysis confirmed that the initial-fixation duration was significantly different in each position (except between P1 and P5), reflecting the fact that the number of fixations was larger at unfavorable positions (P1, P4-P5) than for positions near the middle of the stimulus (P2-P3). Finally, the ANOVA also revealed a Font by Position interaction, just above the significance in analysis with participants as random effects ($F_1(4, 60) = 2.36$, $p = 0.06$) and significant in analysis with item as random effects ($F_2(4, 632) = 2.67$, $p < 0.05$, $\eta_p^2 = 0.02$). As for the initial-fixation duration, we compared the number of fixations in each position in both cursive and printed stimuli with Bonferroni's post-hoc comparisons. The analysis revealed that the number of fixations was not significant between P1 and P4-P5 in

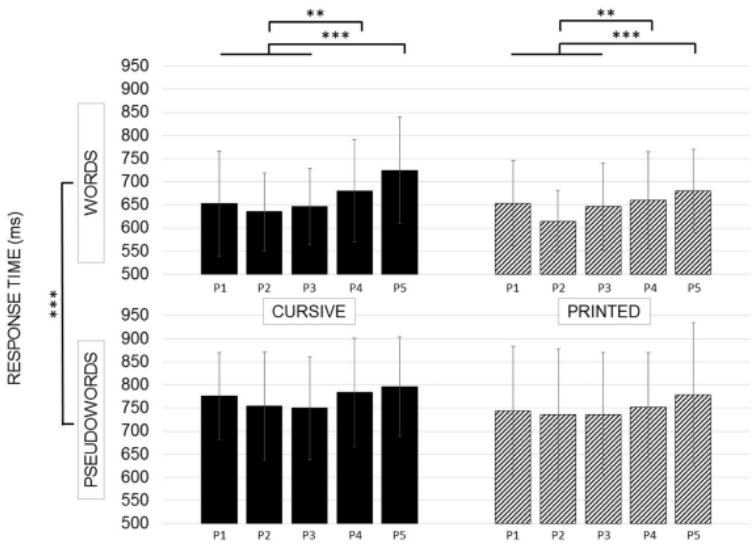

Fig. 3. Response time in adults as a function of the Positions (P1, P2, P3, P4, and P5) and of the Font (cursive and printed) for words (top) and pseudowords (bottom). Error bars correspond to inter-participants SD. $^{**}p < 0.01$; $^{***}p < 0.001$. Note that statistical reports were determined from the effect of Position, including both words and pseudowords in both fonts.

cursive whereas it was not significant only between P1 and P5 in printed (see Fig. 5). Interestingly, the test revealed that the number of fixations in P3 was lower in the printed font than in the cursive font ($p < 0.05$ from F_1; $p < 0.01$ from F_2).

2.2.2.3. Refixation position. The frequency-density of the refixation position was highlighted by the fifth-order polynomial regression. As can be seen in Fig. 6 (black line for the cursive font, $R^2 = 0.87$ and double grey line for the printed font, $R^2 = 0.91$), the distribution curve of the refixation position is more flattened in the cursive than in the printed font.

2.3. Interim discussion

The first experiment revealed that skilled readers were less accurate at recognizing cursive stimuli compared with printed stimuli, while their response times remained unchanged for both types of font.

Eye-movement data in adults revealed that the OVP effects were located near to the center of the stimuli: The initial-fixation duration was higher in P3, the number of fixations was lower in P3, and the frequency-density of refixation position was also around P3.

Did OVP change with the font type in adults? Interestingly, the OVP effects were slightly affected by the font type: both the *initial fixation duration OVP effect* and the *refixation OVP effect* were more pronounced at P3 in the printed font: The initial-fixation duration was higher, the number of fixations was lower and the distribution of refixation

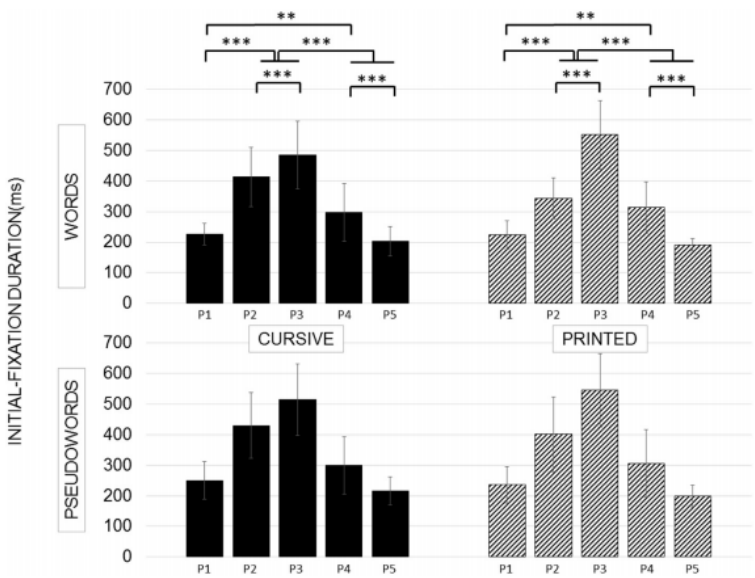

Fig. 4. Initial-fixation duration in the adult group as functions of the Positions (P1, P2, P3, P4, and P5) and of the Font (cursive and printed). Error bars correspond to inter-participants SD. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. Note that statistical reports were determined from the Font by Position interaction, including both words and pseudowords.

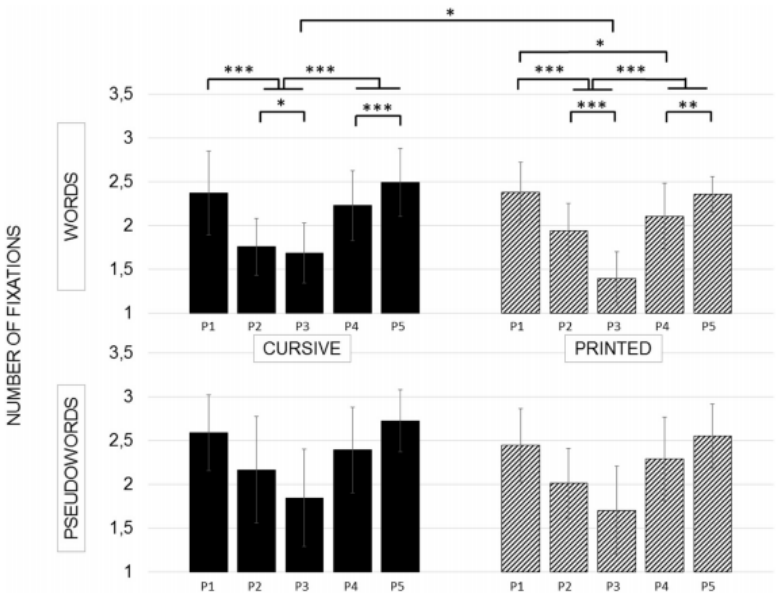

Fig. 5. Number of fixations in the adult group as functions of the Lexicality (words and pseudowords) and of the Font (cursive and printed) in (A), and as functions of Position (P1, P2, P3, P4, and P5) in (B). Error bars correspond to inter-participants SD. $^{*}p < 0.05$; $^{***}p < 0.001$. Note that statistical reports were determined from the Font by Position interaction, including both words and pseudowords.

position was more focused in P3 when recognizing printed stimuli, as compared with cursive stimuli.

To sum up, the overall pattern of the first experiment seems to be a more leftward shift of the OVP effect for cursive stimuli than for printed stimuli (which show a more symmetric curve). The results also show that the accuracy performance (in the lexical decision task) as well as the VP function were slightly modulated by the font. This supports the hypothesis that the identification of cursive stimuli is associated with a reading cost, likely because of the absence of delimitation between characters or segmentation and polysemy difficulties (Ducrot & Pynte, 2002; Gori & Facoetti, 2015; Lorette, 1999). We can also hypothesize that this reading cost is due to a lack of familiarity or practice as this standard font is totally absent from French books.

In a prior study conducted in English, Slattery and Rayner (2010) compared three different fonts in a reading task: one well-known in print (Time New Roman), one less known in print (Harrington), and one less known in cursive (Script MT bold). The authors revealed that the cursive font took longer to read than the well-known print font but there was no significant difference between the cursive and the less known printed font. In the present experiment, no significant difference was found in the RT between the printed and the cursive fonts despite the fact that the former is much better known than the latter. This suggests that motor facilitation associated with the cursive font may compensate for the reading cost associated with the cursive. However, this hypothetical compensation is very slight, probably because skilled readers generally mix cursive and printed fonts when writing. We therefore wondered whether motor facilitation could be at work in participants who day-to-day write by hand in cursive, as is the case with children in primary school. Indeed, in several countries of Latin Europe, such as Italy, Spain or France, pupils learn to write exclusively in cursive. To test this hypothesis, we ran a second experiment, using exactly the same procedure, with second-grade French Children who had exclusively learned to write in cursive. We hypothesized that if motor facilitation does play a role in recognizing words, children who practice solely cursive handwriting would be less disadvantaged when reading the cursive font.

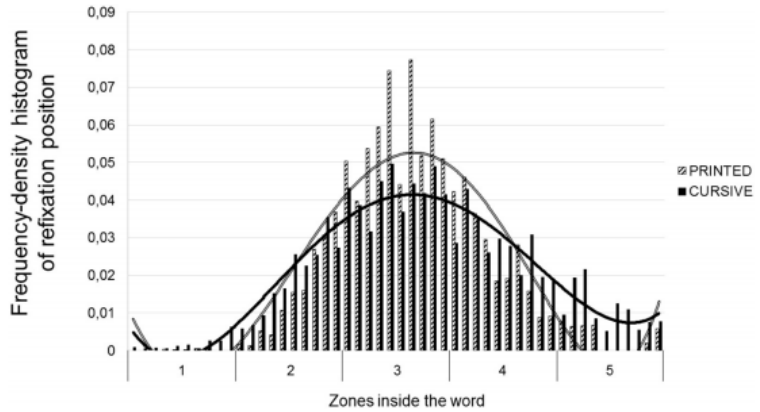

Fig. 6. Frequency-density histogram of refixation position (abscissa) within the stimuli as a function of the Font (cursive and printed).

3. Experiment 2

3.1. Methods

3.1.1. Participants

Sixteen second-graders (mean age 7 years 3 months ± 5 months; 8 females) volunteered for the experiment. They were French native speakers and had normal or corrected-to-normal vision; none suffered from any neurological, psychiatric, or emotional disorders or were educationally disadvantaged. These children were recruited in an elementary school located in Aix-en-Provence, a city in southern France, with their parents' informed consent and the agreement of the board of education. The reading age of all children was tested using the standardized French reading test "L'Alouette" (Lefavrais, 1967). This test evaluates the reading proficiency in terms of both word and non-word decoding and reading speed. It is specifically designed to assess proficiency in rapidly switching between lexical and non-lexical processing while reading text. Since we were interested in normal reading development, children who were considered by their teachers as either having specific learning deficits (i.e., the children with poor reading skills) or behavioral difficulties (i.e., children who exhibited attentional or other behavioral problems in class) were not included in the sample. Furthermore, two children were not included in the analysis because they decided to stop before the end. The mean reading age of the 14 children who completed the experiment (90.7 ± 3.6 months) differed significantly from their corresponding chronological age (86.8 ± 4.8 months; Wilcoxon signed-rank test: $Z(13) = 2.41$, $p < 0.05$), confirming that the selected children were good readers. These children were tested in October, that is, at the beginning of the school year.

3.1.2. Material, task and procedure

The material, the task, and the data analysis were exactly the same as in the first experiment on adults. Note that, among the selected words, 50% of the words were relatively infrequent for children (mean frequency < 16 occurrences per million, *Trésor de la langue française*, 1971), and 50% were frequent (mean frequency > 419 occurrences per million).

3.2. Results

We applied the same criteria as in Experiment 1 to select the data, except that the maximum response time allowed was 4000 ms (against 1500 ms in Experiment 1 with adults). This resulted in a rejection of 12% of the trials. The data exclusion was independent of the experimental conditions.

3.2.1. Lexical decision performance

3.2.1.1. Percentage of correct responses. The ANOVA revealed a main effect of Lexicality only on the percentage of correct responses ($F_1(1, 13) = 6.91$, $p < 0.05$, $\eta_p^2 = 0.35$; $F_2(1, 158) = 15.40$, $p < 0.001$, $\eta_p^2 = 0.09$). As can be seen in Fig. 7, the percentage of correct responses was lower in the words than in the pseudowords (81.1% and 90.4%, respectively). This difference can be explained by the material used in this experiment: 50% of the words were relatively infrequent (16 occurrences per million). Consequently, several infrequent words were considered by children as pseudowords. Finally, the ANOVA did not reveal any effect of Font ($p = 0.29$) nor of Position ($p = 0.90$), nor any interactions ($ps > 0.34$) on the percentage of correct responses.

3.2.1.2. Response time (RT). The ANOVA revealed a main effect of Lexicality ($F_1(1, 13) = 68.31$, $p < 0.001$, $\eta_p^2 = 0.84$; $F_2(1, 158) = 203.95$, $p < 0.001$, $\eta_p^2 = 0.56$) and a main effect of Font ($F_1(1, 13) = 19.57$, $p < 0.001$, $\eta_p^2 = 0.60$; $F_2(1, 158) = 129.31$, $p < 0.001$, $\eta_p^2 = 0.45$) on RT. As can be seen in Fig. 8, the RT was lower in words than in pseudowords (2052 ms and 2599 ms, respectively) and was also lower in printed than in cursive (2186 ms and 2465 ms, respectively). The ANOVA did not reveal any effect of Position ($p = 0.07$), nor any interactions ($ps > 0.07$).

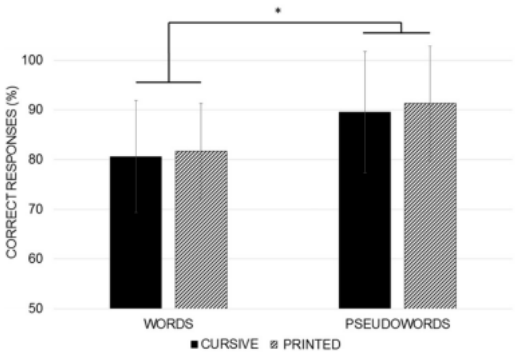

Fig. 7. Percentage of correct responses in children as a function of Lexicality (words and pseudowords) and Font (cursive and printed). Error bars correspond to inter-participants SD. *$p < 0.05$.

3.2.2. Eye-movement measures

3.2.2.1. Initial-fixation duration. The ANOVA revealed a main effect of Font ($F_1(1, 13) = 7.89$, $p < 0.05$, $\eta_p^2 = 0.38$; $F_2(1, 158) = 10.22$, $p < 0.01$, $\eta_p^2 = 0.06$). The initial-fixation was longer in cursive than in printed (364 ms and 336 ms, respectively). The ANOVA also revealed a main effect of Position ($F_1(4, 52) = 41.56$, $p < 0.001$, $\eta_p^2 = 0.76$; $F_2(4, 632) = 146.70$, $p < 0.001$, $\eta_p^2 = 0.48$) and a Font by Position interaction ($F_1(4, 52) = 4.86$ $p < 0.01$, $\eta_p^2 = 0.27$; $F_2(4, 632) = 5.79$, $p < 0.001$, $\eta_p^2 = 0.03$). The post-hoc analysis of the Font by Position interaction revealed that the difference of initial-fixation duration between P2 and the other positions was greater in the printed than in the cursive font. The initial fixation in the cursive font was longer in P2 than in P1 ($p < 0.05$) and was also longer in P1-P2-P3 than in P4-P5 ($p < 0.001$ for all comparisons). For the printed font, the initial fixation duration was longer in P2 than in the four other positions ($ps < 0.001$ for all comparisons),[2] thus suggesting an IOVP effect, that predicts that initial fixation duration is longer when the eyes are at the center of the words or slightly to the left of center. Interestingly, the post-hoc test revealed that the initial fixation in P3 was longer in the cursive than in the printed font.

3.2.2.2. Number of fixations. The ANOVA revealed a main effect of Lexicality ($F_1(1, 13) = 65.74$, $p < 0.001$, $\eta_p^2 = 0.83$; $F_2(1, 158) = 163.69$, $p < 0.001$, $\eta_p^2 = 0.51$): words were identified with lower fixations than pseudowords (4.3 fixations and 5.0 fixations, respectively). The analysis also revealed a mean effect of Position ($F_1(4, 52) = 11.56$, $p < 0.001$, $\eta_p^2 = 0.47$; $F_2(4, 632) = 28.66$, $p < 0.001$, $\eta_p^2 = 0.15$). As can be seen in Fig. 10, the location where the number of fixations was minimal was to the left of the target's center, thus suggesting an OVP effect. The post-hoc tests confirmed that stimuli in P2 were identified with less fixations than stimuli presented at the four others positions ($ps < 0.01$). As for the initial-fixation duration, we compared the number of fixations in each position in both cursive and printed stimuli with Bonferroni's post-hoc comparisons. The tests revealed that the number of fixations was smaller in P2 than in the four other positions in the printed font ($ps < 0.01$). In the cursive font, the difference of fixations was only significant between P2 and P5 ($p < 0.05$).

[2] Note that it was also longer in P3 than in P4 ($p < 0.05$) and P5 ($p < 0.01$), and longer in P1 than in P5 ($p < 0.05$; see Fig. 9).

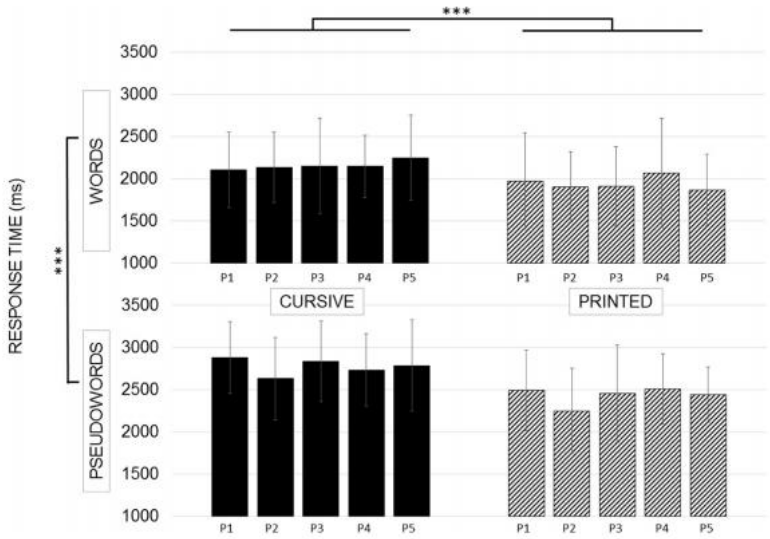

Fig. 8. Response time in children as a function of the Positions (P1, P2, P3, P4, and P5) and of the Font (cursive and printed) for words (top) and pseudowords (bottom). Error bars correspond to inter-participants SD. ***$p < 0.001$.

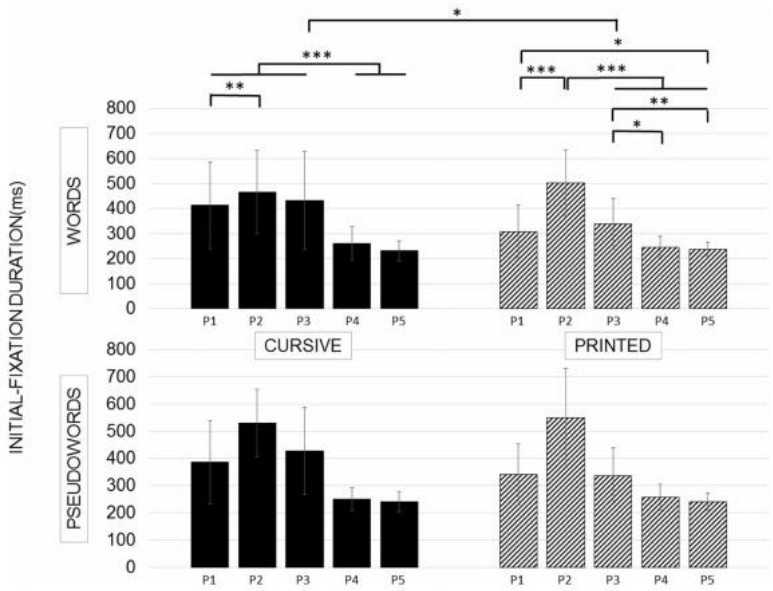

Fig. 9. Initial-fixation duration in children as a function of the Positions (P1, P2, P3, P4, and P5) and of the Font (cursive and printed) for words (top) and pseudowords (bottom). Error bars correspond to inter-participants SD. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Note that statistical reports were determined from the Font by Position interaction, including both words and pseudowords.

3.2.2.3. Refixation position. The frequency-density of the refixation position was highlighted by the fifth-order polynomial regression displayed in Fig. 9 (black line for the cursive font, $R^2 = 0.77$ and double grey line for the printed font, $R^2 = 0.89$). As can be seen in Fig. 11, the refixation position seems to be more variable in the cursive font than in the printed one.

3.3. Interim discussion

Children were observed to be faster in recognizing printed stimuli compared with cursive stimuli, while the accuracy of their responses remained unchanged for the two types of font. Thus, performance measures show that when identifying the stimuli in the two fonts with the same accuracy, children required more time for cursive stimuli. This result is in line with the idea that the identification of cursive stimuli is associated with an increased processing cost.

Eye-movement data in children also revealed that the VP function was affected by the font type. Firstly, a different *IOVP effect* between the two fonts was observed on the initial-fixation durations. In the printed font, the initial-fixation duration was longer in P2[3] than in the four other positions, thus suggesting an IOVP effect that predicts a consistent

[3] The displacement of the OVP from P3 (adults) to P2 in children will be discussed in the general discussion.

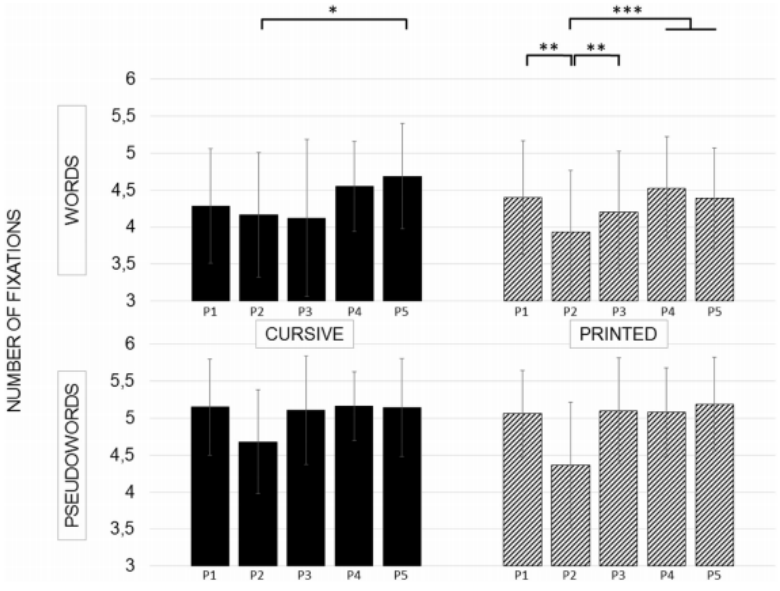

Fig. 10. Number of fixations of children as a function of the Positions (P1, P2, P3, P4, and P5) and of the Font (cursive and printed) for words (top) and pseudowords (bottom). Error bars correspond to inter-participants SD. $*p < 0.05$; $**p < 0.01$; $***p < 0.001$. Note that statistical reports were determined from the Font by Position interaction, including both words and pseudowords.

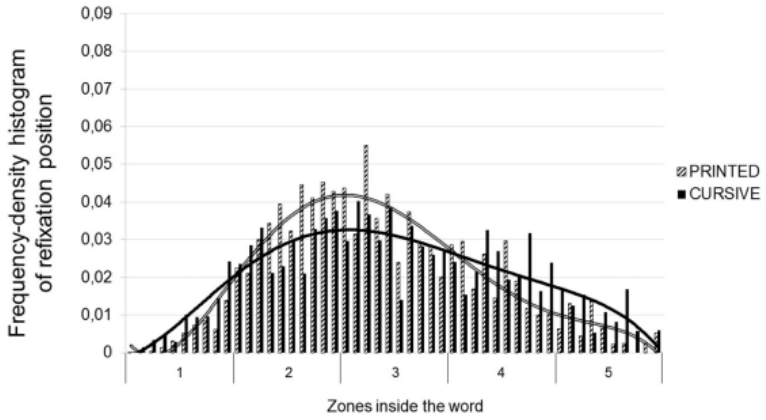

Fig. 11. Frequency-density histogram of refixation position (abscissa) within the stimuli functions of the Font (cursive and printed).

relationship between the initial-fixation location and the initial-fixation duration (Nuthmann et al., 2005; Vitu et al., 2001). When participants first fixated a suboptimal fixation position, the duration was typically short and accompanied by a refixation at the OVP. On the other hand, when participants first fixated close to the OVP, they fixated longer to process the stimulus (see Gagl, Hawelka, & Hutzler, 2014, for similar results). The effect was much less pronounced for the cursive font: Initial fixation duration was only longer in P2 compared with P1 and longer in P1-P2-P3 compared with P4-P5 in the cursive font. Secondly, the number of fixations on a word was lower when the eyes initially fixated just left of the middle of the word (P2) and was greater in the printed than in the cursive font. In the cursive font, the number of fixations did not differ significantly between the four first positions and only P2 differed significantly from P5. This indicates that children benefit from the OVP (to reduce their number of fixations in the stimulus) less in cursive than in the printed font. This finding is strengthened by the distribution curve of the refixation position which was more flattened in the cursive font than in the printed font: In the printed font, children seemed to locate their second fixation mostly around P2 whereas, with cursive stimuli, their refixation location was wider, P2-P3.

To sum up, the results of Experiment 2 (like the results of Experiment 1) support the hypothesis that the identification of cursive stimuli is associated with a higher processing cost when compared to the identification of printed stimuli. The perceptual difficulties inherent to the cursive font are the most important contributing factors to the challenge of word recognition.

4. General discussion

This study has aimed at comparing the impact of the standard cursive and printed fonts on visual word recognition. A variable-viewing-position technique was applied in order to force participants to first fixate a specific zone within a stimulus word. This paradigm was used to precisely observe the effects of the font on the OVP shape, a specific oculomotor marker of reading processing and expertise (Ducrot, Lété, Sprenger-Charolles, Pynte, & Billard, 2003; Lehtimäki & Reilly, 2005).

For both groups the font and stimulus location had a strong effect on lexical-decision performance (1) and on the parameters of basic oculomotor behavior (2).

(1) Beyond a classic improvement of performance in both accuracy and speed in the lexical decision task between children and adults, we observed that recognizing cursive words was less efficient than recognizing printed words, in both adults and children. The font impacted on word recognition speed in children (but not on accuracy) whereas it impacted on recognition accuracy in adults (but not on speed). This different pattern of results may be explained by reading strategies which are respectively careful and risky in children and adults, depending upon the reader's goal (O'Regan, 1992). This hypothesis is consistent with the results reported by Huestegge, Radach, Corbic, and Huestegge (2009) showing that beginning readers adopt a more careful eye-movement strategy (i.e., fixated closer to the beginning of the stimuli) than older children.

(2) Previous eye-movement research has established that, when the eyes first fixate a non-optimal spot for word recognition (word beginning or end), it makes sense to exit early from the non-optimal spot and program a saccade to a more optimal location in the word. In our study, we found evidence, for both groups, of such eye behavior in a lexical decision task. The number of fixations in the target word increased when the initial fixation was forced onto the word beginning or ending rather than to the left of the word center, and this is similar to a refixation OVP effect (Gagl et al., 2014; Nuthmann et al., 2005; Vitu et al., 2001). This effect translated also into an IOVP effect on the first fixation durations: When readers first fixated optimally, the initial fixation durations were longer, and less likely to be followed by a subsequent fixation. The OVP curve was modulated by reading exposure since OVP and IOVP effects were located in P2 for children and P3 for adults. The leftward shift of the OVP (and IOVP) function probably reflects the fact that the useful information for beginning readers is located at the beginning of the word. Beginning readers might stick to serial reading. From this perspective, word beginnings are reasonable targets for the initial fixation. In that vein, O'Regan and Jacobs (1992) reported a more central OVP effect for short and frequent words in expert readers (see also O'Regan et al., 1984).

It is generally assumed that the main cause for the OVP effect lies in the very strong decline in visual acuity, even within the fovea (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989). But an important result of the present study is that the OVP effect for isolated words was also influenced by the font. More specifically, both groups exhibited a cost for the cursive font with a more flattened OVP shape. This cost was more pronounced in children for whom the time required for recognizing cursive words was longer than that for recognizing printed words. Note that the slight shift in the OVP curve caused by the cursive font was in the opposite direction in children and adults: the OVP function shifted leftward for adults and rightward for children (to cover a wider area, P2-P3) with cursive stimuli.

4.1. A reading cost associated with the cursive font: evidence of a predominant role for the spacing between characters

The results, obtained in both adults and children, indicated that participants were less efficient in word recognition with the cursive font than with the printed font. This is likely due to the fact that the processing of the cursive font involves a large number of perceptual difficulties. Prior research has demonstrated the important role of interletter spaces in saccade computation (Ducrot & Pynte, 2002). It has been hypothesized that initial landing positions are determined by an eye-guiding mechanism based on low-level perceptual processing that detects the presence of spaces between characters. When the stimulus is discrete, the reader takes the direction of visual exploration into account and attempts to land left of center (for a left-to-right language), in preparation for subsequent left-to-right attentional scanning. When the stimulus turns out to be continuous, no attentional scanning is implemented. In the case of the cursive font, with the absence of physical delimitation between letters, participants were unable to use between-character spacing to guide eye movements and the within-word eye behavior was disrupted by the continuousness of cursive stimuli (even though the stimuli used were *character-based* strings). This interpretation is also in line with the hypothesis proposed by Lorette (1999) claiming that the processing of a cursive font involves strong segmentation difficulties. Moreover, this is also in agreement with several studies that have shown that the OVP effect gradually strengthens as inter-letter spacing, and hence letter eccentricity increase (Nazir et al., 1992; Nazir et al., 1998).

Finally, narrow spacing may produce character confusion between some letters (Liu & Arditi, 2000; Lorette, 1999). The point-of-spread function imitates the actual visual image of the retina, which is somewhat blurred. When inter-letter spacing decreases, some letters tend to merge together in this blurred picture. This result can also be linked to the fact that handwritten characters produce more lateral masking, leading to a crowding effect (Gori & Facoetti, 2015; Pelli et al., 2007). Whether the OVP pattern is influenced by letter visibility and letter position coding (Grainger, 2017; Stevens & Grainger, 2003) remains an open question in the case of cursive.

4.2. No modulation resulting from writing practice in children?

A second question of the study was whether the font effect depends on the writing practice. Contrary to our hypothesis, we cannot conclude that children who practice cursive writing gain a sufficient motor facilitation to observe that the cursive font is easier than the printed font when recognizing words. We cannot completely rule out the possibility that the children were not sufficiently familiar with the standardized cursive font. According to the well-known common coding approach (e.g., Prinz, 1997), it is widely accepted that visual recognition of an action depends on the observer's motor familiarity with the action (e.g., Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). In the case of writing, Wamain, Tallet, Zanone, and Longcamp (2012) examined the modulation of the visual event related potential (ERP) evoked by letters of different levels of motor familiarity: self-handwritten by the observers, written by other individuals or printed. They applied a dual-task in which the participants had to simultaneously perform a letter orientation discrimination task (correct or mirror orientation) and a self-paced wrist extension. They revealed that the reaction time for mirror letter presentation was lower for handwritten letters than for printed letters only when the letters were self-handwritten, a finding corroborated by electrophysiological data suggesting a gradual change of some components of the visual ERPs related to the letter's motor familiarity. Furthermore, in this study we tested a cursive font and not a self-handwritten font. Thus, it should be noted that the extent to which children would be more or less efficient in recognizing their own handwriting compared to the printed font remains an open question.

A second and complementary hypothesis that could explain why we did not observe a beneficial effect of the cursive font is that children are becoming more and more familiar with the printed font. Digital writing devices associated with the use of computers, tablets or smartphones are increasingly replacing the pen (e.g. Kiefer & Velay, 2016). Consequently, children handwrite in cursive and typewrite in printed fonts. These two modes of writing lead them to read the both fonts. Furthermore, the school books used to learn to read are almost all published with a printed font, leading their visual system, like that of adults, to become more expert in reading the printed than the cursive font.

4.3. Conclusions

These results indicate the important role of the presence (or absence) of spaces between characters in guiding the within-word

behavior during visual word recognition. Neither the writing practice in children, nor the reading expertise in adults could compensate for the impact of the perceptual difficulty induced by the cursive font. The practical applications of these findings are significant: French children who exclusively learned to write in cursive recognized printed words more quickly than cursive words. The interest of learning to write in the cursive font is thus questionable, knowing that the cursive font is slower than the printed (Bara & Morin, 2013). The arguments resulting from the embodied cognition theories that we reported in the introduction to justify a possible advantage in writing the cursive font (e.g., Longcamp et al., 2005) do not justify its upholding. Conversely, we suppose that learning to read and write a single and unique font would facilitate the transfer between these two literacy skills.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2018.06.003.

Funding

This work, carried out within the Labex BLRI (ANR-11-LABX-0036) and the Institut Convergence ILCB (ANR-16-CONV-0002), has benefited from support from the French Government, managed by the French National Agency for Research (ANR), under the project title DYSTAC-MAP (ANR-13-APPR-0010).

Conflicts of interest

None.

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