Original Article

Exploring Immediate Memory and Its Influencing Factors Among Young Arabic Readers: Insights from Letter and Symbol Recall Performance

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ABSTRACT

Few studies have examined the performance of recalling Arabic letters. Some studies suggest that the low recall performance of Arabic letters may be attributed to the inherent visual complexity of Arabic script, while others highlight poor visual attention abilities among Arabic readers. In this context, the present study focuses on investigating immediate memory and the factors influencing its capacity among young Arabic readers. Immediate memory refers to the number of letters an observer can recall in a free recall task. Three experiments were conducted to examine the effects of exposure time (50, 100, and 200 ms), letter spacing (0.04°, 0.36°, and 1°), and stimulus type (acquired vs. non-acquired). Acquired stimuli consisted of Arabic and Latin letters, whereas non-acquired stimuli included Amazigh letters. It is noteworthy that our participants had no prior exposure to the Amazigh language. The results revealed significant effects of exposure time, letter spacing, and stimulus type on performance in the free recall task. In light of these findings, the study provides a discussion of factors that may account for the low recall performance observed in previous research.

Keywords

Immediate memory; visual attention; free recall; letters; symbols

1. INTRODUCTION

Sperling's first work [1] introduced the immediate memory as the number of letters an observer can retain during a brief exposure. Indeed, the results of the first three experiments in this study indicated that exposure time, spatial distribution, and the number of letters in the stimulus did not affect the size of immediate memory. Based on the free recall task, Sperling suggests a limited immediate memory capacity of up to 5 letters. On the other hand, using the partial report task showed that the observer had access to the entire stimulus. In the partial report task, Spreling relied on presenting a matrix of three rows and three or four columns, followed by a sound signal indicating the line to be reported. The results showed that the observer could recall more letters in the partial recall task (9 to 12 letters), thus underlining the superiority of partial recall over free report. Similarly, Averbach and Coriell [2] used the partial report task with two-line

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letter arrays and showed that participants had access to the whole stimulus. These early works emphasized the passive retention of sensory information and thus contributed to the introduction of iconic memory [1,3]. Appropriately, Colheart's work proposed two forms of memory, sensory and non-sensory[4-6]. Sensory memory is characterized by a high storage capacity with a fairly limited lifespan (i.e., iconic memory). On the other hand, non-sensory memory has limited storage capacity lasting a few seconds (i.e., durable storage)[7,8].

Numerous studies have subsequently emphasized the contribution of attention processes to the transfer of visual information from iconic to working memory [9-12]. Indeed, work has shown that the build-up and erasure of iconic memory [13] appears to be affected by changes in attentional loading [14,15]. Inspired by pioneering work on visual memory [1,2], Valdois, Bosse, and Tainturier [16] proposed the visual attention span task to assess visual attention capacities in reading. The visual attention span refers to the number of items that can be retrieved simultaneously in a single fixation [17]. In the free recall task, participants are asked to report letters regardless of location [1]. In the partial report task [2], participants must report only the cued letter after the stimulus has disappeared.

Given the verbal aspect involved in letter recall, several studies have addressed the role of verbal short-term memory and phonological abilities in visual attention span tasks. Findings have revealed that deficits in visual attention span (VAS) may be present in dyslexic individuals, even when their linguistic skills and verbal short-term memory are intact [18,19]. Considering the contribution of phonological abilities in recall tasks, results remain divergent. On one hand, some studies have shown a dissociation between phono- logical difficulties and visual attention [20-22]. Conversely, the use of verbal (numbers and letters) and non-verbal (symbols) stimuli in partial recall tasks [23] revealed performance differences between dyslexic subjects and normal readers only with letter stimuli. In a similar vein, a recent study conducted with German students showed a correlation between visual attention and phonological awareness, thereby challenging the visual attention span hypothesis [24]. These works [23,24] suggested a strong involvement of the grapheme- phoneme conversion system in partial recall tasks. However, Castet, Descamps, Denis-Noël, and Colé [25] reported that the poor performance of dyslexic subjects in partial recall tasks was not attributable to cluttering or a deficit in the grapheme-phoneme conversion system, suggesting instead a deficit in attentional processes at the iconic memory level. Indeed, research on symbol string processing in dyslexics has yielded divergent results, with some studies reporting a deficit [18,19,26] while others found no significant difference [18,23,27]. It is noteworthy that these studies employed various experimental paradigms, yet this diversity did not adequately explain the observed discrepancies in results [19,28]. For instance, even when the same paradigm was employed, opposing results were reported [26,27]. In their study, Yeari *et al.*[18] found similar performance between typical readers and those with reading difficulties, suggesting that the low performances observed in dyslexics in other studies [26,27] might be influenced by the presence of comorbid attention deficit hyperactivity disorder (ADHD) not accounted for. Faced with these discrepancies, some authors [28,29] have recommended the use of symbols not corresponding to known verbal labels and the control of the effect of visual familiarity.

Similarly, the use of letters and symbols in recall or identification tasks has highlighted the first letter advantage. Many work suggest that learning to read contributes to the elongation of receptive fields to the left and therefore propose the modified receptive fields hypothesis (MRF) as an explanation for the first letter advantage[30-32]. For example, Tydgat and Grainger[31] revealed significant differences in performance between letters and symbols at the initial position of sequences presented in the central vision. Similarly, Chanceaux and Graigner [30] show that letter identification performance was better than that obtained for symbols at the most eccentric position in the left visual field (LVF). In the same vein, other results [32] supported the superiority of letters over symbols and indicated that increasing the spacing between symbols contributes to improved target identification rates. It is worth mentioning that the debate surrounding the nature of the first-letter advantage is still open. Indeed, other studies using the global word paradigm [33] have shown that the first-letter advantage remains valid even when words have been presented vertically and have proposed the redirection of attention to the beginning of the word as a possible explanation for the first-letter advantage. Recently, Castet *et al.* [34] revealed a significant performance difference between letters and symbols, while also unveiling a "W" shaped pattern similar for both types of stimuli. Consequently, Castet *et al.* [34] challenge the propositions of proponents of the receptive field modification hypothesis, suggesting instead that the processing of letters and symbols occurs based on representations already stored in memory. They also suggest that the performance differences observed between letters and symbols could be explained by a familiarity difference, as suggested by other previous works [35-37].

In the Arabic context, few studies have focused on evaluating the recall and/or identification performance of Arabic letters. For instance, Pelli *et al.* [38] suggest that the identification of Latin letters was more efficient than that of Arabic and Chinese letters. Similarly, the conclusions of Eviatar *et al.* [39] support the idea that reading Arabic orthography poses more difficulties than reading Hebrew orthography among participants proficient in both languages. Moreover, the study by Ibrahim *et al.* [40] revealed that participants proficient in both Arabic and Hebrew were faster when stimuli consisted of Hebrew letters. However, investigating the effect of visual complexity of Arabic letters in the visual attention span task among Arabic readers has yielded contradictory results. For example, Awadh *et al.* [41] showed that the recall rate of letters in the visual span task was affected by the visual complexity of Arabic letters among fourth and fifth-grade students. The authors revealed a significant relationship between performance in the threshold identification task and recall tasks (free recall and partial recall). Controversially, no significant relationship was found among expert Arabic readers [42].

To better discuss the divergent results reported by previous studies, we relied on two recommendations. The first one lies in the choice of unknown symbols [28], for which we recruited a sample of Arabic speakers with no knowledge of Amazigh letters. The second recommendation concerns the use of the free recall task. Indeed, this choice is based on three essential points. Firstly, this task has already been used to assess visual attention skills in reading [17]. Secondly, whether free or partial, recalls are made from representations already stored in memory [34,43]. The third point concerns the misunderstanding of the well-established strong correlation between scores in free and partial recall tasks [41,42].

2. METHODOLOGY

2.1. General method

2.1.1. Viewing distance, letter size, and monitor

In all experiments, the viewing distance was 50 cm, and letters were presented in black on a white background by a Courier bold font. Letters subtended approximately visual angles 0.27°. Note that the shape of the letters in Arabic did not allow for fixing letters 'x-height' (i.g. 'ج' and 'ب'). The stimuli were presented on a Lenovo monitor (Model: ideopad100; VGA: Intel(R) Iris (TM) Graphics 5100; refresh rate: 60.003 Hz; resolution: 1366 - 768).

2.1.2. Stimuli and procedure

The stimuli used contained no repeated letters and never corresponded to the skeleton of a real word. At the beginning of each trial, a fixation point was presented for 500 ms. After its disappearance, the sequence was displayed. For each condition, ten trials were performed.

2.1.3. Measures

Two measures were calculated. The first measure was based on the identity of the letter reported (FR). The second measure was based on the identity and location of the letters in the sequence (SR).

2.2. Experiment 1: Letter spacing effect on immediate memory span size

2.2.1. Participants, Stimuli, and Procedure

Nine subjects aged 11 to 13 years (M=11.77, SD=0.83) participated in the experiment. All participants had a normal or corrected-to-normal vision. Three letter-spacing conditions were used, an 'A' condition (approximate standard spacing of S=0.04°), a 'B' condition (S = 0.36°), and a 'C' condition' (S = 1°). At the beginning of each trial, a central fixation point was presented for 500 ms. Then, a 5-consonant string centered on fixation was displayed for 200 ms—a total number of trials of 30 trials, ten trials for each condition. Participants had to report verbally as many letters as possible immediately after the string disappeared.

2.3. Experiment 2: Exposure time effect on immediate memory span size

2.3.1. Participants, Stimuli, and Procedure

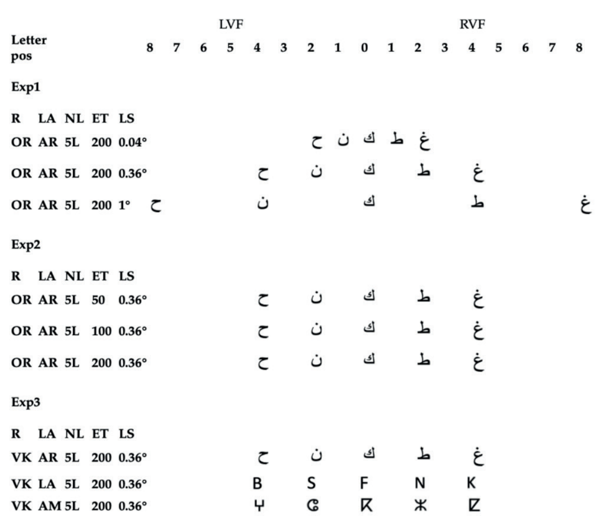
Nineteen subjects aged 11 to 13 years (M=11.82, SD=0.65) participated in the experiment. All participants had a normal or corrected-to-normal vision. Stimuli were 5 Arabic letter strings. The letter spacing was set to 0.36° (condition B in the letter-spacing experiment). Three exposure times (50, 100, and 200 ms) were used. At the beginning of each trial, a central fixation point was presented for 500 ms. Then, the 5-letter string centered on fixation was displayed—30 trials, ten for each exposure time. Participants had to report verbally as many letters as possible immediately after the string disappeared.

2.4. Experiment 3: Stimulus nature effect on immediate memory span size

2.4.1. Participants, Stimuli, and Procedure

Fourteen subjects aged 11 to 14 years (M=12, SD= 0.87) participated in the experiment. All participants had a normal or corrected-to-normal vision. Stimuli were 5 Arabic, Amazigh, and Latin letter string letters. The Arabic letters were formatted to have approximately the same width as the Tifinagh and Latin letters. The letter spacing was set to 0.36°. The 5-letter strings were of similar width in the three languages. Note that our participants did not follow any Amazigh language course. At the beginning of each trial, a central fixation point was presented for 500 ms. Then, the 5-letter string centered on fixation was displayed for 200 ms. Then, a visual keyboard was displayed. Participants had to report the 5-letter strings using the visual keyboard—30 trials, ten for each exposure time.

Figure 1. Diagram of stimulus parameters in the three experiments: letter spacing (LS), exposure duration (ET), language (LA). OR and VK correspond to oral recall and recall using visual keyboard



2.5. Result

2.5.1. Experiment 1: letter-spacing

A general linear mixed effects model (GLMMs), using the glmer function (R Core Team, 2020) with letter-spacing (cond A vs. cond B vs. cond C), recall type (FR vs. SR), and letter position in the string (P1 vs. P2 vs. P3 vs. P4 vs. P5), showed a significant effect of letter-spacing ($\chi^2(2) = 35.59$, $p < 0.001$), recall type($\chi^2(2) = 46.95$, $p < 0.001$), and letter position($\chi^2(4) = 1759.52$, $p < 0.001$). Pairwise comparisons show that performance in condition A (S=0.04°) was better than in conditions B (S = 0.36°) (Estimate=0.466, SE=0.099, z= 4.705) and C (S = 1°) (Estimate=0.55, SE=0.099, z=5.56). No significant differ- ence was revealed between conditions B and C (Estimate=0.0861, SE=0.097, z=0.880). The comparisons show that the performance obtained in the serial recall (SR) was lower than that obtained in the free recall (FR) (Estimate=-0.558, SE=0.081, z=-6.853). Regarding the position effect, pairwise comparisons showed significant differences in the performance obtained between all positions, except between positions P1 and P2 (Estimate=0.144, SE=0.162, z=0.891). Similarly, pairwise comparisons between the three letter-spacing conditions sug- gest that differences in the probabilities of correct response were driven by differences in performance in position P4. Analyses show better performance in the ’C’ condition (0.04°) compared to those obtained in ’B’ condition (0.36°) (Estimate=1.132, SE=0.194, z= 5.835) and ’C’ condition (1°) (Estimate=0.971, SE=0.187, z= 5.183) conditions. No difference in performance was revealed between the three conditions at the P1, P2, and P3 positions.

Table 1. Recall rate across the tree letter-spacing conditions

Recall type	LS (0.04°) Mean(SD)	LS (0.36°) Mean(SD)	LS (1°) Mean(SD)
Free recall	3.20 (0.58)	2.96 (0.35)	2.94 (0.28)
Serial recall	2.93 (0.53)	2.64 (0.36)	2.56 (0.45)

2.5.2. Experiment 2: Exposure time

A general linear mixed effects model (GLMMs), using the glmer function (R Core Team, 2020) with exposure time (50 vs. 100 vs. 200 ms), recall type (FR vs. SR), and letter position in the string (P1 vs. P2 vs. P3 vs. P4 vs. P5) as fixed effects, and participants as a random effect, shows a significant effect of exposure time ($\chi^2(2) = 33.03$, $p < 0.001$), recall type ($\chi^2(1) = 186.84$, $p < 0.001$), and letter position ($\chi^2(4) = 3535.56$, $p < 0.001$). Pairwise comparisons showed better recall performance with an exposure time of 200 ms than with exposure times of 100 ms (Estimate=-0.358, SE=0.063,

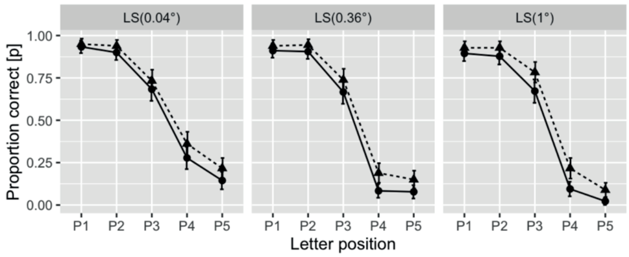


Figure 2. Probability correct responses as a function of letter-spacing, recall type and letter position. Triangles and squares represent free recall (FR) and serial recall (SR), respectively. Error bars indicate 95% confidence intervals.

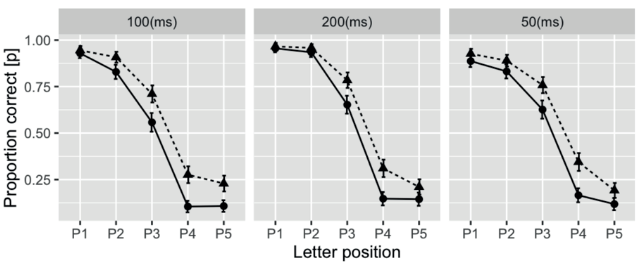


Figure 3. Probability correct responses as a function of exposure time, recall type and letter position. Triangles and squares represent free recall (FR) and serial recall (SR), respectively. Error bars indicate 95% confidence intervals.

z=-5.61) and 50 ms (Estimate=0.249, SE=0.063, z= 3.909). No significant difference was found between the performances obtained in the 50 and 100 ms exposure times (Estimate=-0.109, SE=0.063, z=-1.71). The performance obtained in serial recall (SR) was lower than that obtained in free recall (FR) (Estimate=-0.726, SE=0.053, z=-13.66). Considering the position effect, the analyses show that all comparisons were significant between the five positions. Pairwise comparisons showed that the differences in performance between the three exposure times were driven by differences in the first two positions, P1 and P2. The results of the comparisons show that the performance obtained in the 200ms exposure time was superior to that obtained in a 50ms exposure time in positions P1 (Estimate=0.955, SE=0.224, z=4.260) and P2 (Estimate=1.103, SE=0.195, z=.670). No difference in performance was revealed between the two exposure times in position P3 (Estimate=0.137, SE=0.117, z=1.171).

Table 2. Recall rate across the tree exposure times

Recall type	50 ms Mean(SD)	100 ms Mean(SD)	200 ms Mean(SD)
Free recall	3.11 (0.38)	3.06 (0.31)	3.22 (0.38)
Serial recall	2.62 (0.46)	2.52 (0.40)	2.83 (0.38)

2.5.3. Experiment 3: Stimulus nature

A general linear mixed effects model (GLMMs), using the glmer function (R Core Team, 2020) with language (Arabic vs. Latin vs. Amazigh), recall type (FR vs. SR), and letter position in the string (PL2 vs. PL1 vs. PC vs. PR1 vs. PR2) as fixed effects, and participants as a random effect, shows a significant effect of language ($\chi^2(2) = 916.40$, $p < 0.001$), recall type ($\chi^2(1) = 142.61$, $p < 0.001$), letter position ($\chi^2(4) = 2172.49$, $p < 0.001$), and language*letter position interaction ($\chi^2(8) = 217.40$, $p < 0.001$). Pairwise comparisons using the Tukey method show poor performances in Amazigh compared to Arabic (Estimate=-2.011, SE=0.085, z=-23.528) and Latin (Estimate=-2.182, SE=0.089, z=-24.289). No significant difference in performance was found between Arabic and Latin letters (Estimate=-0.059, SE=0.071, z=-0.82). The comparisons showed that the performance obtained in the free recall (FR) was superior to that obtained in the serial recall (SR) (Estimate=-0.718, SE=0.061, z=-11.64). The decomposition of the interaction effect suggests significant differences in the performance obtained in positions PC and PL2 in Arabic (Estimate=2.842, SE=0.165, z=17.22) and in positions PC and PR2 in Latin stimuli (Estimate=2.41, SE=0.158, z=15.27) stimuli. On the contrary, no difference in performance was revealed between the PC and PR2 positions for the Amazigh stimuli (Estimate=0.158, SE=0.213, z=0.745). Considering the performances obtained at the level of the initial letter (PL2), our analyses show that the only significant difference that was revealed between the two types of report (FR vs. SR), was in the Amazigh stimuli (Estimate=-0.834, SE=0.215, z=-3.869). No significant performance difference between the two types of report (FR vs. SR) was revealed, at the positions (PR2) and (PL2) in Arabic (Estimate=-0.589, SE=0.369, z=-1.593) and Latin (Estimate=-0.53, SE=0.46, z=-1.131) stimuli, respectively.

Table 3. Recall rate across the tree languages

Recall type	Arabic Mean (SD)	Latin Mean (SD)	Amazigh Mean (SD)
Free recall	3.00 (0.44)	3.03 (0.38)	1.49 (0.34)
Serial recall	2.58 (0.58)	2.64 (0.46)	0.89 (0.43)

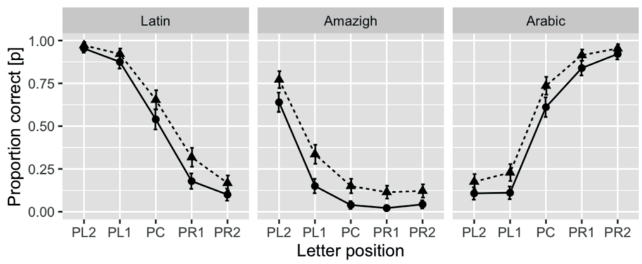


Figure 4. Probability correct responses as a function of language, recall type and letter position. Triangles and squares represent free recall (FR) and serial recall (SR), respectively. Error bars indicate 95% confidence intervals.

2.6. Discussion

Overall, the three experiments show that participants recall an average of three letters in the free recall task (FR) among the studied population, corroborating previous findings [41]. This observation indicates that the recall rate in our Arabic sample is lower than that found in a French study [53]. In that study, the authors demonstrated that fifth-grade students recalled 4.4 letters in the free recall task. In lighy of theses observation, the presents results support the previously observed narrowing in visual attention span observed among expert Arabic readers [42].

The experiment[1] results show that increasing the letter-spacing contributes to a decrease in free recall rate. According to the analyses, the difference observed between the three spacing conditions (0.04°, 0.36°, and 1°) was marginally driven by differences in the recall rates of letters occupying the position (P4). This result can be considered as a two-sided coin. On one hand, this reflects the validity of the hypothesis suggesting that the size of the visual attention window influences recall performance [42,44]. Bundesen [45] suggests that visual attentional capacity is modulated by visual short-term memory [7,8,46,47] and visual processing speed. In addition, the MTM model [48] proposals suggest that the speed of processing written words depends on the size of the visual attention win- dow. In our case, we cannot explain these differences by effects related to short-term visual memory [7,8,46,47]. We, therefore, suspect that the shift in the visual attention window toward the beginning of the sequence in both conditions, 0.36° and 1° weakened the recall rate. On the other hand, and even though the free recall task was designed to assess the contribution of visual attention in the reading task [17,42,44], the present results may also support those of Chung *et al.* [49]. In the latter study [49], the authors indicate a significant effect of letter spacing on reading speed (using the RSVP paradigm) translated by a neg- ative correlation between reading speed and letter-spacing. Similarly, Yu and colleagues [50] varied the letter-spacing of trigrams (using the trigram task[51] and concluded that the decreased reading speed resulted only from a reduced visual span size. Furthermore, our findings also corroborate those of Castet *et al.*[34]. In the latter study, the authors used two types of spacing, the first being similar to that used in the study by Tydgat *et al.*[31], while the second was twice as wide as the first. The results show that performance was better when the spacing was small. Based on our analyses, we would like to draw attention to two observations of great importance. The first is the similar recall performance obtained at the P3 position under all three conditions (0.04°, 0.36, and 1°). At the same time, the second observation lies in the increased recall performance of the letter occupying position P4 in the most crowded condition (0.04°). The first observation is at odds with the proposals of the founders of the visual attention span, suggesting that allocating more spacing minimizes the effects of crowding[17]. Perhaps this observation seems to be valid only in the case of partial report [31,52]. On the other hand, the second observation aligns perfectly with proposals suggesting that visual attention capacity is modulated, in the first instance, by the size of the visual attention window [17,45,48,53]. In light of this, a possible explanation for the increased recall rate at position P4 in the most crowded con- dition (0.04°) suggest that the letter at position (P4) fell into the spotlight of spatial attention.

Experiment 3 aims to study the effects of the nature of the stimulus (Learned vs. Un- learned) on the free recall rate. For this purpose, we used Arabic, Latin, and Amazigh letter sequences. It should be noted that only participants who had yet to take any Amazigh language learning course were recruited in this experiment. In good agreement with the proposals of the proponents of the visual attention span suggesting an effect of reading di- rection in the free recall task, opposite patterns were found for Arabic and Latin sequences. Given the suggestions of a body of work [38-40] pointing to the complexity-related effects of Arabic letters on letter identification, we expected the recall rate to be relatively lower for Arabic letters compared to that obtained for Latin letters. For example, the results of Pelli *et al.* [38], show that the identification of Latin letters was more efficient than that of Arabic and Chinese letters. Similarly, a recent work by Awadh *et al.*[41], highlights the effect of the visual complexity of Arabic letters on the recall rate. In the latter study, the authors revealed a significant relationship between performances on the threshold identification task and the recall tasks (free recall and partial recall). Controversially, the present results indicate similar recall performance in Arabic and Latin sequence (see Table 3). In light of the present results and those of Awadh *et al.* [42] suggesting no correlation in performance between the threshold identification task and the free recall task in Arabic skilled readers, we suggest that visual complexity cannot account for the observed shrinkage in visual attention span size in Arab readers.

The debate on the contribution of verbal short-term memory and phoneme-grapheme correspondence to the recall task remains open. For example, work on the partial recall task has produced divergent results. The work of Ziegler, Pech-Georgel, Dufau, and Grainger [23] in dyslexic subjects supports a substantial contribution of grapheme-phoneme cor-respondence in the partial report task. In contrast, Castet, Descamps, Denis-Noël, and Colé [25] rule out any contribution from the grapheme-phoneme conversion system and suggest that the poor performance observed is due to a visual attention disorder. Similarly, work on symbol string processing suggests divergent results. Some studies have found similar performance in normal and dyslexic readers [19,26,28,29], while others have re- ported poorer performance in dyslexic subjects than in normal readers [24,54? ?]. Our results show better recall performance for learned stimuli (Arabic and Latin letters) than for unlearned stimuli (Amazigh letters) (see Table 3), and corroborate the results of earlier work [35,37,55]. However, we rule out visual complexity [38-40] and familiarity [35-37] as possible explanations for the lower recall rates for symbol strings (Amazigh letters) in the present study. Indeed, visual complexity cannot account for the observed differences. As mentioned earlier, results show similar performances of letter recall in both languages (Arabic and Latin). Therefore, if the decrease in the recall rate in the symbol strings was due to visual complexity, we should have differences in performance between the Arabic and Latin strings in the first place. Similarly, this decrease in performance cannot be explained only by familiarity (or expertise) effects [35-37]. If this were the case, our analysis should not reveal a dramatic drop in performances at the PL1 and PC positions in the symbol strings. Figure 4 shows that the differences in performance between learned (Latin letters) and unlearned (Amazigh letters) stimuli were huge at positions PL1 and PC compared to those found at position PL2. One possible explanation for the poor recall performance of symbol strings suggests that stimuli whose phonological form has already been learned were temporarily better retained in verbal short-term memory than those with no learning traces (Amazigh letters)[23]. In an earlier study, Holding [56] compared the recall perfor- mance of Arabic and English letters in American and non-native Arab subjects. The results showed poor recall performance in the American group in Arabic letter sequences. Based on this result, Holding contradicted the hypotheses suggesting passive storage of visual information and proposed immediate visual information processing. Moreover, Holding indicated low rates of Arabic letter recall in non-native Arabic participants (an average of 1.52 and 0.65 letters in free and partial recall, respectively). The author explained this drop in performance to second-language influences and poor recall strategies (left of right fashion for Arabic letters) and similarly dismisses influences linked to the complexity of the Arabic script. In a good match, our findings and those of Awadh *et al.* [42] show that native Arabic participants could report more letters (in a right-to-left fashion).

It is known that the debate about the nature of the first letter advantage is still open. In this respect, the literature has proposed two explanations. The first explanation suggests a modification of the visual receptive fields for alphabetic stimuli [30], while the second supports the contribution of visual attention processes [33]. The hypothesis (MRF) suggests that learning to read contributes to a leftward elongation of receptive fields in the left visual field (LVF) [30,32]. For example, Chanceaux and colleagues showed that symbols were misidentified as letters at the most eccentric position in the left visual field (LVF). In contrast, Aschenbrenner *et al.* [33] have used the global word paradigm, and showed that the first letter advantage remains valid during vertical word presentation and proposed rapid deployment of visuospatial attention to the beginning of the word as a possible explanation for this advantage. In good agreement with the hypothesis of a rapid redirection of attention to the beginning of the sequence, our analyses of the third study (experiment 3), whether for the Arabic, Latin, or Amazigh sequences, show better performances at the initial positions PL2 and PR2 in comparison with those found in the central position PC of the sequence. At the same time, significant differences in recall performance at the initial position (PL2) between the Latin and Amazigh sequences (languages read from left to right) have been revealed. If we consider the Amazigh letters as symbols (because, as we have just pointed out, our participants did not know the names of the letters), this last result may support the propositions of Grainger and colleagues [32]. In this study, the authors [32] varied the spacing size in letter and symbol sequences. The results show a superiority of letters over symbols in the left visual field (LVF) at the first position (the eccentric position P1) and indicate that allocating more spacing contributes to increasing the identification rate of the symbol occupying the eccentric position in the left visual field (LVF). Although this last result favors the proposal of the receptive field modification hypothesis (MRF), we decided to discuss our results with those of previous works [24,31,52].

As a whole, the data from studies on normal and dyslexic adults [31,52], and normal and dyslexic children [24] show a typical "W" pattern for letters and an "inverted V" pattern for symbols. For letters, the best recall performance was obtained in the initial position (P1) compared to those found in the third position (P3). For symbols, the peak performance was only obtained at position (P3) (the central position of the stimulus). Similarly, our data show higher performance in the initial position (PR2 and PL2) than in the third position (PC) of the sequences. On the other hand, for the symbols (Amazigh letters), the only difference with the patterns found in the previous studies [24,31,52] is that the peak of performance was obtained at the initial position (PL2) of the sequence (see Figure 4). Based on this comparison and our findings, we suspect the contribution of visual attention [2] in the appearance of performance differences at the initial position (P1) in the previous studies [24,31,52] for two respects. On the one hand, the free recall task supports a shift of attention toward the beginning of the sequence. On the other hand, the results show that localization errors at the the first position (PL2) were only revealed in the Amazigh sequences. Two criticisms can be addressed to our proposal. The first criticism is that the eye movements in the free recall task were not controlled. We point out that the results of the work on eye movements during reading [57] and on the letter recall task suggest that the exposure time of 200 ms did not allow for a saccade [42]. Another argument in favor of an attentional shift not coupled with an eye movement finds support in the significant difference in performance observed between the two measures (FR and SR) at the level of the initial position (PL2) for the Amazigh stimuli. If our participants fixed the first letter of the sequence, our analyses should reveal similar recall performances. The second criticism, therefore, lies in the paradigm used in the present experiment (the free recall task). Although the body of work on the first letter advantage (or serial position effect) has used partial recall or forced choice tasks (2AFC), the patterns in the study by Tydgat *et al.* [31] showed better performance for letters occupying the initial position P1 compared to those found at position P3 of the sequence. In other words, although the forced choice paradigm (2-AFC) was designed to minimize the effects of memory and Guessing [58], the signature of free recall (the left-to-right fashion) also emerged in Tydgat *et al.*'s [31] data (see Experiments 1 and 2). This observation remains valid even when the authors used a partial recall task [24,31,52]. In the same vein, we would like to indicate that the debate about the relationship between the performances obtained in the free and partial recall tasks [17,41,42,44,53,59] remains open. Another argument supporting the contribution of high-level processes (i.e., visual attention and visual memory) in the emergence of the first letter advantage finds support in the work of Castet *et al.* [34]. Although Castet *et al.*' results [34] showed a significant difference in performance between letters and symbols, the same "W" pattern for letters and symbols was found. In light of this, Castest *et al.* [34] challenge the proposals of the proponents of the modification of receptive fields hypothesis while indicating that the processing of both letters and symbols takes place on representations already stored in memory [60].

We devote this final section to discussing some hypotheses that might help explain the poor letter recall performance revealed by Awadh *et al.* [42] among expert Arab readers. In this respect, we want to draw attention to two points of great importance. The first is the poor performance of expert Arab readers in the partial report task. Even though this task involves recalling a single letter, the results of Awadh *et al.* [42] show differences in recall performance between Arab and Latin (French and Spanish) participants. The second point lies in the strong correlation between the scores obtained in the two free and partial report tasks [17,41,42,44,53,59]. Bundesen [45] proposes that visual attention capacity is modulated by visual processing speed and visual short-term memory capacity. Given the present results (see Table 3) and those of Awadh *et al.* [42], we rule out the visual complexity of Arabic letters as a possible explanation for poor recall performance, hence the contribution of visual processing speed. As suggested by Castet *et al.* [34], the visual short-term memory contains two types of memory. The iconic memory has a short duration (500ms) and a large storage capacity (9 to 12 items). A working memory with a small storage capacity (around five items) but long-lasting (several seconds).

The first hypothesis (H1) assumes that the reduced performance of Arabic readers in the partial report task may be due to a limitation in iconic memory capacity. The problem with this hypothesis (H1) is that the capacity of iconic memory is large (up to 9-12 items), while the stimulus size in the Awadh *et al.* [42] study was at most five letters. A second hypothesis (H2) points to a weakness in Arabic readers' attentional processes in transfer- ring information from iconic memory to durable storage (working memory). Indeed, in a comparative study of normal and dyslexic children, Castet *et al.* [25] showed that poor performance on the partial recall task in dyslexic subjects was strongly linked to a deficiency in the attentional processes involved in transferring visual information to durable storage and stated that the narrowing of the visual attention span (VAS) in dyslexic subjects was just another name for the deficit in the attentional transfer of IM-VSTM information. We refute the hypothesis (H2) as an explanation for the poor performance observed in Arab readers [42] for two reasons. The first reason lies in the performance patterns found among Arab participants in the partial report task. Although the performance was lower than that of Latin readers, the same performance curve shape was found. Similarly, the performance curves of the Arab participants in the partial recall task had the same shape as those found in the dyslexic subject (i.e., Laurent) with a phonological disorder [61]. The second points to the absence of the positional effect previously found (at positions P2 and P4) in the partial recall task in the dyslexic subject (i.e., Nicolas) suffering from a visual attention disorder [61]. Based on these observations, we suggest that if the lower performance in Arab readers was due to a weakness in attentional transfer processes, the performance curves in the partial recall task must have reflected at least one marker or signature of some weakness (i.e., the positional effect previously found in surface dyslexia). In contrast, the curves of the Arab participants show that all five sequence elements were processed simultaneously (parallel processing). We, therefore, suggest that poor performance in the VAS task cannot be explained by a weakness in the attentional processes involved in IM-VSTM transfer.

We wish to emphasize once again the findings of the study by Awadh *et al.* [42]. The performance curves of the Arab participants in the free recall task exhibited a similar pattern to those observed in a dyslexic subject named Nicolas, who has a visual attention disorder [61]. Although skilled Arab readers [42] and Nicolas [61] were not matched in terms of chronological age, recall performance remained lower at the last two positions, PL2 and PL1. Two hypotheses can be put forward. The third hypothesis (H3) suggests that Arab readers processed the entire sequence but struggled to recall the last two letters. The fourth hypothesis (H4) proposes that Arab readers only recalled letters within the visual attention window. Based on the results of the partial report task and the performance patterns outlined in the study by Awadh *et al.* [42], we reject the fourth hypothesis (H4) as similar performances were observed for outward letters PL2 and PR2 [42]. In other words, if the poor performance of Arab readers was due to a reduction in the size of the visual attention window, we would have also observed significant differences in the performance of letters at positions PL2 and PR2 in the partial report task. Therefore, we lend more weight to the third hypothesis (H3) and contemplate a detailed discussion, drawing on propositions suggesting the contribution of short-term verbal memory to the partial report task.

In an earlier study, Sperling [43] proposed the contribution of auditory information storage (AIS) to recalling visual stimuli, and suggested that immediate memory seems to be limited by the capacity of the AIS-Rehearsal component. It is possible that Arabic readers may suffer from a reduced AIS-Repetition component capacity (H3). Given that most Arabic letters have a "CVC" form, the phonetic demands of Arabic letters could be more onerous in terms of pronunciation time and articulation programming than those of Latin letters. However, we reject the hypothesis (H3) for three reasons. The first reason lies in the similar recall performances observed for Arabic and Latin letters (Exp3 - Stimulus Nature). The second reason stems from the results of the second experiment (Exp2 - Exposure Time). In contrast to previous propositions [1], suggesting that the size of immediate memory is independent of exposure time, our results demonstrate that decreasing the exposure time from 200 to 50 ms decreases the size of immediate memory. The third reason arises from the findings of the first experiment (see Figure 2), indicating that shifting visual attention to the beginning of sequences in conditions B (0.36°) and C (1°) decreases free recall rate (especially at position P4). While Sperling posits that the observer can perceive the entire stimulus and that the AIS repetition component limits the size of immediate memory, our current results contradict the previous hypothesis (H3) and suggest that the limitation of immediate memory in Arabic readers seems to be more influenced by visual attention capacity [42] than by the capacity of the AIS repetition component [43]. Our results thus support Holding's propositions [56], suggesting that the observer can only process the letters selected for attention. The lower recall performance in visual attention span tasks [42] among skilled Arabic readers may also indicate a slow shift of visual attention (H5). The results of the second experiment (Exp2 - Exposure Time) show that the decrease in recall rate in short exposure time (i.e., 50 ms) is mainly due to a decrease in recall rates at the first two positions P1 and P2 of the sequence (see Figure 3). In sum, our findings suggest that the decline in recall performance among Arabic readers [42] necessitates further research investigating hypotheses of slower build-up (H6) or faster erasure (H7) of visual information in iconic memory [13] before the transfer from iconic memory to visual short-term memory occurs.

ABBREVIATIONS

The following abbreviations are used in this manuscript:

MRF Modified receptive fields VAS Visual attention span
FR Free recall
SR Serial recall

AIS Auditory information storage
IM-VSTM Iconic memory- Visual short-term memory

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