OPTIMAL VIEWING POSITION EFFECT OF CONNECTING AND UN-CONNECTING LETTERS WITHIN LETTER-STRING IN ARABIC

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Abstract
The current study investigates the role of Arabic letter visibility as a possible cause of the Optimal Viewing Position-OVP effect. We used connecting and un-connecting Arabic letters of different shapes (basic, initial, medial, final) placed at the various possible positions within connecting letter string of ل (ل) (Experiment 1) and within un-connecting letter string of ا (ا) (Experiment 2). In order to investigate whether performance on the visual identification task is modulated by letter type, we presented each of the connecting and un-connecting letter targets in each of the ten stimulus positions across the array so as to produce a mean RT (ms) for each of the letter types. Using the initial fixation paradigm enabled us to compare Reaction times with correctly identified letter targets appearing in the different possible positions within letter-string.

The findings of the present experiments demonstrated that visual letter recognition is influenced by: (i) the letters’ type (connecting, un-connecting), as connecting letters are easier to recognize than un-connecting letters; and (ii) letters’ shape (basic, initial, medial, final), as medial and final are harder to recognize than basic and initial letter shapes, (iii) letter string’s type, as reading rates were longer for letter stimuli that have been embedded within a connecting letter string compared to an un-connecting letter string with inter-letter spacing, (iv) visual field, as reading rates were longer for letter stimuli that have been presented in LVF compared to RVF, (v) eccentricity, as letter reading rates were correlated with its eccentric placement across the letter string.

Keywords: Arabic, Crowding, Optimal viewing position, Visual recognition, Connected/Un-connected.

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1. INTRODUCTION

It is now generally accepted that visual word recognition in languages with alphabetical orthographies involves identity processing of a word’s component letters. Thus, text cannot be read if letters or words are not resolved (Falkenberg, Rubin, & Bex, 2007). Several researchers also agree that much of this processing should be performed in parallel (e.g., Grainger, 2008; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981).

Adelman et al. (2010) showed that among adult readers, letter identity encoding starts during the first 25 ms of printed word processing for all string positions simultaneously. However, the authors showed that while processing was initiated over the whole word letter string in parallel, all letters were not identified at the same level of efficiency (Reilhac, Jucla, Iannuzzi, Valdois & Démonet, 2012).

What factors influence our ability to identify letters? This question is important because it will help develop our understanding of the very first phase of reading processes during which visual feature information is mapped (in parallel) onto position-coded letter identities in both central and peripheral vision (Grainger & van Heuven, 2003; Marzouki et al., 2013).

One particularly useful approach for addressing this issue is to examine the process of letter identification within letter strings. In this way, we can gather information about letter-level processing while minimizing the influence of higher-level phonological and semantic processes. The assumption here is that during visual word recognition, some form of letter-level processing must be performed before higher order codes come into play (Grainger, Granier, Farioli, Van Assche, & van Heuven, 2006; Grainger & van Heuven, 2003).

One well-established phenomenon in research investigating letter string perception is that when fixating on the center of a letter array, performance is optimal for the central letter, and then, drops as a function of eccentricity (Averbach & Coriell, 1961; Butler, 1975; Butler & Merikle, 1973; Haber & Standing, 1969; Merikle, Coltheart, & Lowe, 1971; Merikle, Lowe, & Coltheart, 1971; Mewhort & Campbell, 1978; Nazir, Ben-Bouayab, Decoppet, Deutsch, & Frost, 2004; Schwantes, 1978; Stevens & Grainger, 2003; Wolford & Hollingsworth, 1974). This reflects a drop in visual acuity as a function of distance from fixation (Taydgat & Grainger, 2009).
Under some conditions, alphanumeric characters that are reliably identified in isolation can no longer be identified, when closely surrounded by other optotypes or contours (Bouma, 1970; Pelli et al., 2004; Pelli & Tillman, 2008). This effect is known as crowding, lateral interference, or local contour interaction (Falkenberg, Rubin, & Bex, 2007). The effect of lateral interference on letter identification is a well-studied phenomenon in experimental psychology, with results showing that target letters flanked by other letters to the left and/or right are harder to identify than isolated letter targets (e.g., Bouma, 1970; Huckauf & Nazir, 2007; Grainger et al., 2010). More recently, effects of lateral interference have been integrated within a wider perspective of crowding effects on the processing of various types of visual stimuli (e.g., Pelli et al., 2004; Pelli & Tillman, 2008; see Levi, 2008; Whitney & Levi, 2011, for reviews). However, the vast majority of these studies have limited their investigation to the effects of stimuli that are closest to the target and have shown that target-flanker separation determines target identification accuracy. Much of this work can be summarized by Bouma’s law (Bouma, 1970; Pelli & Tillman, 2008), which states that critical spacing (i.e., the target-flanker separation that allows target identification at a criterion level of accuracy) is a linear function of target eccentricity. Therefore, it is possible that crowding reduces visibility of adjacent letters or words (or increases spatial interference among them); this is the process that likely slows reading (Falkenberg, Rubin, & Bex, 2007).

The importance of understanding mechanisms involved in letter identification within a letter string has been well illustrated by a recent finding showing that increased letter spacing can facilitate reading in children with dyslexia (Perea et al., 2012; Zorzi et al., 2012). Indeed, crowding is one factor known to have a large influence on letter-in-string perception, and manipulating inter-letter spacing modulates the amount of crowding. In the present study, we focused on one specific aspect of crowding effects—the contribution of flanking element type (connecting, un-connecting)—while examining possible interactions between crowding effects and visual acuity during Arabic letter identification.

Another main finding from previous research on letter identification is that there is an asymmetry in the visibility of letters to the left and right of fixation (Bouma, 1973; Kajii & Osaka, 2000; Nazir, 1991; Nazir, Heller, & Sussmann, 1992; Nazir, Jacobs, & O’Regan, 1998). Nazir et al. (1992) measured letter visibility at various distances from the left and right of fixation. A drop in recognition performance depended not only on the distance from a fixation but also on the side of the presentation. At the same distance from fixation, letters to the
right of fixation were easier to recognize than letters to the left. This asymmetry in letter perception was previously reported by Bouma (1973) for the first and last letters of nonsense strings and has since been replicated for letters embedded in digits (Kajii & Osaka, 2000). The present study assessed this phenomenon with Arabic letters.

2. THE PRESENT STUDY

The present study provides a further exploration into the role of Arabic letter visibility as a possible cause of the optimal viewing position (OVP) effect. Bouma (1973) tested identification of the initial and final letters of random letter strings (e.g., dvxmk) with the entire string presented to the left or right visual field. Nazir et al. (1992) measured the visibility of letters embedded in a series of Xs. However, the letters did not appear at every possible position in the series, and fixation was only at the first or last letter in the series. Kajii and Osaka (2000) measured identification of letters embedded in digits, but once again, the entire string was presented to the left or right of a central fixation point (in their horizontal display condition). Finally, traditional studies of letter-in-string visibility (e.g., Estes, Allmeyer, & Reder, 1976) used only central fixations. Thus, to date, there are no studies providing complete measures of Arabic letter visibility across all combinations of fixation positions and letter-in-string positions. Our study was designed to address this gap, while building on the classic work in this field in an attempt to highlight some key, unresolved issues. We used connecting and un-connecting Arabic letters of different shapes (basic, initial, medial, and final) placed at various possible positions within connecting letter strings of ٖ (ل) (Experiments 1) and within un-connecting letter strings of ٖ (ل) (Experiments 2). In order to investigate whether performance on the visual identification task was modulated by letter type, we presented each of the connecting and un-connecting letter targets in each of the ten stimulus positions across the array to produce a mean RT (ms) for each letter type. Using an initial fixation paradigm enabled us to compare RTs with correctly identified letter targets appearing in different possible positions within a letter-string.

The present study assessed precisely what factors are at play during the computation of letter identities in the earliest phases of letter perception and whether this processing does, indeed, depend on peripherally un-fixated vision. This was of special interest when the OVP paradigm was employed to investigate Arabic language with its unique visual features of connectedness (Table 1).
The processes used for identifying letters within letter strings are adaptive to the nature of the script to which the reader is exposed during reading acquisition (Pitchford & Lefgeway, 2008). One feature of an alphabetic orthography, such as Arabic, that may be extracted through a process of statistical learning is the frequency with which letters appear within words (i.e., how often a particular letter occurs in words, per se; Pitchford & Lefgeway, 2008). Arabic connecting letters are of higher frequency (22 letters out of 28), than un-connecting letters (6 letters out of 22) occurring in words. In previous studies, significant negative correlations were found between the RT needed to detect a target letter and letter frequency. If letter frequency is an orthographic property that influences the identification of letters within letter strings, RTs should be faster for identifying connecting target letters appearing in the string compared with un-connecting target letters that are least frequent in written words.

The contribution of crowding among Arabic letters has not been systematically studied; it remains unclear whether changes in letter type and letter string type influence letter identification. Furthermore, a letter within a letter string is (necessarily) at differing eccentricities. Thus, it is possible that part of the decline in visual or perceptual span performance will be attributed to changes in acuity or crowding with eccentricity.

Clearly, if crowding (as defined by Pelli, Palomares, & Majaj, 2004) is a key factor affecting letter recognition, then recognition of isolated letters will be affected by crowding to a lesser extent than letters presented within a letter string. In particular, the type of letter string (connecting, un-connecting) will determine the amount of lateral masking, and crowding interference will be larger for connecting letter stings than un-connecting letter strings. Next, we argue that the pattern of results found in the present study might be understood by considering the constraints imposed on a specialized system for processing strings of letters in Arabic. The key mechanism behind this account is crowding (see Levi, 2008, for a recent review), and the central hypothesis is that crowding affects connecting and un-connecting letters differently.

However, this letter identification is unlikely to be due to a single process. We assume that one possible interpretation of the phenomenon is that it reflects the conjoint influence of three factors: (a) the drop in visual acuity as a function of distance from fixation, (b) the amount of lateral interference (crowding) determined by the number of flanking letters (Bouma, 1970, 1973; Estes, 1972; Estes, Allmeyer, & Reder, 1976; Haber & Standing, 1969; Van der Heijden, 1992),
and (c) the difference in inter-hemispheric processing. Because of the first factor, letter recognition becomes worse for letters that are farther from fixation. Because of the second factor, recognition of letters flanked by a letter on each side is worse than for letters with only one flanking letter. Due to the third factor, recognition of letters presented to the right of fixation is better than letters presented to the left of fixation.

Table 1. Letter stimuli used in the different experiments.

<table>
<thead>
<tr>
<th>Basic</th>
<th>Connected Letters</th>
<th>Unconnected Letters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Medial</td>
</tr>
<tr>
<td>1</td>
<td>صد</td>
<td>صد</td>
</tr>
<tr>
<td>2</td>
<td>صو</td>
<td>صو</td>
</tr>
<tr>
<td>3</td>
<td>صز</td>
<td>صز</td>
</tr>
<tr>
<td>4</td>
<td>صر</td>
<td>صر</td>
</tr>
<tr>
<td>5</td>
<td>صغ</td>
<td>صغ</td>
</tr>
<tr>
<td>6</td>
<td>صع</td>
<td>صع</td>
</tr>
<tr>
<td>7</td>
<td>صذ</td>
<td>صذ</td>
</tr>
<tr>
<td>8</td>
<td>صا</td>
<td>صا</td>
</tr>
<tr>
<td>9</td>
<td>صق</td>
<td>صق</td>
</tr>
<tr>
<td>10</td>
<td>صف</td>
<td>صف</td>
</tr>
<tr>
<td>11</td>
<td>صغ</td>
<td>صغ</td>
</tr>
<tr>
<td>12</td>
<td>صض</td>
<td>صض</td>
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<tr>
<td>13</td>
<td>صص</td>
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<td>14</td>
<td>صض</td>
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<tr>
<td>15</td>
<td>صث</td>
<td>صث</td>
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<tr>
<td>16</td>
<td>صس</td>
<td>صس</td>
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<tr>
<td>17</td>
<td>صع</td>
<td>صع</td>
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<tr>
<td>18</td>
<td>صخ</td>
<td>صخ</td>
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<tr>
<td>19</td>
<td>صب</td>
<td>صب</td>
</tr>
<tr>
<td>20</td>
<td>صث</td>
<td>صث</td>
</tr>
<tr>
<td>21</td>
<td>صض</td>
<td>صض</td>
</tr>
<tr>
<td>22</td>
<td>صب</td>
<td>صب</td>
</tr>
</tbody>
</table>

The hypotheses address the following: peripherally-non-fixated connecting/un-connecting Arabic letters level within connecting letter strings and un-connecting letter strings, at all ten possible letter fixation locations. For the study questions related to the peripherally-non-fixated connected/un-connected Arabic letter level, we addressed the following:

1. Is readability affected by visual differentiations of the connecting/un-connecting letterforms within a letter-string in Arabic in the peripherally-non-fixated letter position? We expect that the un-connecting letters will be named faster than the connecting letters as the former have almost the same basic shape in every word position. Alternatively, the naming of connecting letters may be faster than the un-connecting letters because
these letters are more frequent in words than un-connecting letters. This pattern supports a letter frequency effect of letter recognition.

(2) Is connecting/un-connecting letter readability affected by visual eccentricity in Arabic? We expect that the recognition performance for letters will be a function of distance from fixation. Reaction times for letters will increase as a function of eccentricity. This pattern supports the visual acuity drop effect of letter recognition.

(3) Is connecting/un-connecting letter readability affected by the visual field presentation in Arabic? We expect that recognition performance for letters presented in the right visual field (RVF) will be better than for letters presented in the left visual field (LVF). This pattern supports the inter-hemispheric processing differentiation effect of letter recognition.

3. EXPERIMENT 1

Since a letter appears frequently within a multi-letter string, the present experiment addressed the influence of the visual complexity of Arabic orthography on letter identification OVP. More specifically, we assessed how connecting (or un-connecting) letters presented in all possible left or right visual fields within a multi-letter string of un-connecting letters would affect their identification. Thus, the goal of the present experiment was to explore the OVP of connecting vs. un-connecting letters within a multi-letter string of un-connecting letters in Arabic. An initial fixation paradigm was used to present letters in the two visual fields (left, right), according to their position in the word (basic, initial, middle, and final), and within all letter fixation positions (1, 2, 3, 4, and 5). Participants were asked to read (recognize) each presented letter. Participants’ performance was measured according to accuracy rates and RTs for each letter condition. The main experimental question was whether the OVP of Arabic letters within a multi-letter string of un-connecting letters is dependent on letter type (connecting, un-connecting), letter shape (basic, initial, middle, or final), and visual field presentation (left, right).

3.1. METHOD

3.1.1. Variables

The independent variables were letter type (connecting vs. un-connecting), letter shape according to its position in the word (basic, initial, middle, and final), visual field (left, right), and initial fixation letter position (1, 2, 3, 4, and 5). The
dependent variables were accuracy rate and RTs for correct recognition. The experimental matrix was a within-subjects quadric-factorial $2 \times 4 \times 2 \times 5$ design.

![Diagram](image)

**Figure 1.** Example of how letter position was manipulated in the left visual field (LVF) and right visual field (RVF).

3.1.2. Participants

A total of 22 university students participated in this experiment (average age: 22.2, SD = 3, 10 males and 12 females). All were native Arabic speakers, from a middle range of socio-economic status, right-handed, displayed normal or corrected-to-normal vision in both eyes, and had no history of neurological or emotional disorders. No participant was formally diagnosed as having reading impairments.

3.1.3. Stimuli

The stimuli were 2 lists of 22 letters each according to word type (connected, un-connected) and presented in all letter shapes according to its position in the word (basic, initial, middle, and final) (Table 1). The un-connecting letter (١) was not used because letters were in white 24 Simplified Arabic Fix font embedded.
within a multi-letter string of 11 un-connecting " | " (اااا ب اااا) on a black background displayed on a PC screen. The letters were presented randomly.

3.1.4. Procedure

A CRT display was placed at a viewing distance of 60 cm from the participant. The total number of trials was 960. Each trial contained the following steps:

1) Two vertical fixation lines were presented in the middle of the screen for 300 ms.
2) The letter stimulus within a multi-letter string of 11 un-connecting " | " (اااا ب اااا) was presented for 150 ms between the lines with the letter that was to be fixated on placed in all five initial letter fixation positions for each visual field.
3) The fixation lines remained on the screen until a voice key registered a response or until a time-out of 1,500 ms was reached (Fig. 1). A break was provided after 30 trials or whenever the participant indicated that (s)he needed a break.

![Figure 2. Time course of one trial in the letter central fixation task.](image)

Participants received notice that there would be an Arabic letter within a letter-string. The importance of fixating between the two lines, when these lines were presented, was stressed explicitly and repeatedly. Participants were asked to name the letters as quickly and as accurately as possible. Participants were informed that they could ask for a break whenever they wanted.
Each participant was tested individually with a random presentation sequence of the letters. The experimenter wrote the letter noted by the participant.

3.2. RESULTS

Accuracy percentage rates exceeded 99% in all conditions; therefore, an accuracy analysis was not conducted. Differences in reading latencies between the two types of letters listed in the 2 lists according to shape and position in the word (basic, initial, middle, and final), visual field (left, right) and the initial fixation letter position (1, 2, 3, 4, and 5) were analyzed with a repeated measures ANOVA.

The effect of letter type (connecting vs. un-connecting) was significant (F (1,21) =10.56, p < 0.005). Reaction times for the connecting letters (Mean = 474, SD = 103) were shorter than for the un-connecting letters (Mean = 494, SD = 105).

The effect of letter position (basic, initial, middle, and final) was significant (F (3,19) = 9.59, p < 0.0005). Reaction times for the medial position letters were similar to the final position letters but longer than for the basic and initial position letters (Fig. 3, Table 2).

The effect of visual field (left, right) was significant (F (1,21) = 4.85, p < 0.05). Reaction times for letters presented in the right visual field (Mean = 475, SD = 103) were shorter than for letters presented in the left visual field (Mean = 493, SD = 109).

The effect of letter fixation position (1, 2, 3, 4, and 5) was significant (F (4,18) = 34.53, p < 0.0001). Reaction times increased as the fixation letter position increased from 1 to 5 in both visual fields (Fig. 4, Table 3).

None of the interactions were significant.

<table>
<thead>
<tr>
<th>Table 2. Reaction times as a function of letter shape according to its position in a word (basic, initial, middle, and final).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter Shape According to its Position in a Word</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>468</td>
</tr>
</tbody>
</table>
The readability of connecting/un-connecting letters within un-connecting letter strings was affected by visual eccentricity in Arabic. As expected, recognition performance for letters was dependent on distance from fixation. Reaction times for letters increased as a function of eccentricity. This pattern
supports the visual acuity drop effect of letter recognition. In addition, the readability of connecting/un-connecting letters was affected by visual field presentation. As expected, recognition performance for letters presented in the right visual field (RVF) was better than for letters presented in the left visual field (LVF). This pattern supports the inter-hemispheric processing differentiation effect of letter recognition. However, the effect of connecting/un-connecting letter position within un-connecting letter strings by visual eccentricity in Arabic was identical in RVF and LVF.

4. EXPERIMENT 2

Since a letter appears frequently within a multi-letter string, the present experiment addressed the influence of the visual complexity of Arabic orthography on letter identification OVP. Specifically, we were interested in how connecting (or un-connecting) letters presented in all possible left or right visual field positions within a multi-letter string of connecting letters would affect their identification. Thus, the goal of the present experiment was to explore the OVP of connecting vs. un-connecting letters within a multi-letter string of connecting letters in Arabic. An initial fixation paradigm was used to present letters in the two visual fields (left, right), in all letter fixation positions (1, 2, 3, 4, and 5), and according to their position in the word (basic, initial, middle, and final). Participants were asked to read (recognize) each presented letter. Participants’ performance was measured according to accuracy rates and RTs for each letter condition. The main experimental question was whether the OVP of Arabic letters within a multi-letter string of connecting letters is dependent on their type (connecting, un-connecting), their shape (basic, initial, middle, or final) and visual field presentation (left, right). This is the first experiment to assess whether the OVP of Arabic letters within a multi-letter string of connecting letters is modulated by the visual features of connected and unconnected Arabic letters, their shape (basic, initial, middle, or final), the visual field presentation (left, right), and the consequences for the higher cognitive functioning needed for reading.

4.1. METHOD

4.1.1. Variables

The independent variables were letter type (connecting vs. un-connecting), letter shape according to its position in the word (basic, initial, middle, and final),
visual field (left, right), and the initial fixation letter position (1, 2, 3, 4, and 5). The dependent variables were accuracy rates and RTs for correct recognition. The experimental matrix was a within-subjects quadric-factorial $2 \times 4 \times 2 \times 5$ design.

### 4.1.2. Participants

A total of 32 university students participated in this experiment (average age: 23.3, SD = 5, 10 males and 22 females). All were native Arabic speakers, from a middle range of socio-economic status, right-handed, displayed normal or corrected-to-normal vision in both eyes, and none had a history of neurological or emotional disorders. In addition, no participant was formally diagnosed as having reading impairments.

### 4.1.3. Stimuli

The same stimuli from Experiment 1 were used except that the connecting letter (ل) was not used because the letters were in white 24 Simplified Arabic Fix font embedded within a multi-letter string of 11 connecting "ل ل ل ب ل ل ل (الل لل لل لل لل لل لل لل لل لل لل لل لل لل لل لل لل ل)" on a black background displayed on a PC screen.

### 4.1.4. Procedure

The procedure was the same as Experiment 4 except that stimuli were letters within a multi-letter string of 11 connecting "ل ل ل ب ل ل ل (الل لل لل لل لل لل لل لل لل لل لل لل لل لل لل لل لل لل ل)" presented in all five initial letter fixation positions for each visual field and the total number of trials was 960.

### 4.2. RESULTS

Accuracy percentages exceeded 99% in all conditions; therefore, an accuracy analysis was not conducted. The differences in reading latencies between the two types of letters listed in the 2 lists according to their shape in the word (basic, initial, middle, and final), visual field (left, right) and the initial fixation letter position (1, 2, 3, 4, and 5) were analyzed with a repeated measures ANOVA.

The effect of letter type (connecting vs. un-connecting) was significant (F (1,31) = 12.94, p < 0.005). Reaction times for the connecting letters (Mean = 490, SD=105) were shorter than for the un-connecting letters (Mean = 508, SD = 107).

The effect of letter position (basic, initial, middle, and final) was significant (F (3,29) = 4.64, p < 0.01). Reaction times for the medial position letters were similar to the final position letters but longer than for the basic and initial position letters (Fig. 5, Table 4).
The effect of visual field (left, right) was significant ($F\ (1,31) = 4.56,\ p < 0.05$). Reaction times for letters presented in the right visual field (Mean = 494, SD = 105) were shorter than for letters presented in the left visual field (Mean = 504, SD = 102).

The effect of letter fixation position (1, 2, 3, 4, and 5) was significant ($F\ (4,28) = 30.68,\ p < 0.0001$). Reaction times for the letter increased as the fixation letter position increased (Fig. 6, Table 5).

No interactions were significant.

Table 4. Reaction times as a function of letter shape according to its position in a word (basic, initial, middle, and final).

<table>
<thead>
<tr>
<th>Letter Shape According to its Position in a Word</th>
<th>Basic</th>
<th>SD</th>
<th>Initial</th>
<th>SD</th>
<th>Medial</th>
<th>SD</th>
<th>Final</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>489</td>
<td>105</td>
<td>492</td>
<td>100</td>
<td>507</td>
<td>111</td>
<td>508</td>
<td>108</td>
</tr>
</tbody>
</table>

Figure 5. Reaction times as a function of letter shape according to its position in a word (basic, initial, middle, and final). Note: Error bars represent standard error.
Table 5. Reaction times as a function of letter position (1, 2, 3, 4, and 5).

<table>
<thead>
<tr>
<th>Letter Position</th>
<th>Letter-1</th>
<th>SD</th>
<th>Letter-2</th>
<th>SD</th>
<th>Letter-3</th>
<th>SD</th>
<th>Letter-4</th>
<th>SD</th>
<th>Letter-5</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>465</td>
<td>102</td>
<td>479</td>
<td>100</td>
<td>494</td>
<td>105</td>
<td>521</td>
<td>113</td>
<td>537</td>
<td>111</td>
</tr>
</tbody>
</table>

Figure 6. Reaction times as a function of letter position (1, 2, 3, 4, and 5). Note: Error bars represent standard error.

The readability of connecting/un-connecting letters within connecting letter strings was affected by visual eccentricity in Arabic. As expected, recognition performance for letters was dependent on the distance from a fixation. Reaction times for letters increased as a function of eccentricity. This pattern supports the visual acuity drop effect of letter recognition. In addition, the readability of the connecting/un-connecting letters was affected by visual field presentation. As expected, recognition performance for letters presented in the right visual field (RVF) was better than for letters presented in the left visual field (LVF). This pattern supports the inter-hemispheric processing differentiation effect of letter recognition. However, the effect of connecting/un-connecting letter position within connecting letter strings by visual eccentricity in Arabic was identical in RVF and LVF.

5. JOINT ANALYSIS
A joint analysis with the peripheral-unfixated letter presentation RTs of Experiments 1 and 2 was conducted. The within-subjects factor was letter eccentricity (1, 2, 3, 4, and 5 letters to fixation) and the between-subjects factor was letter string type (connecting, un-connecting) as manipulated in Experiments 1 and 2, respectively. The mixed-design ANOVA revealed a significant effect of letter eccentricity effect (F (1,73) = 33, p < 0.0001). Reaction times increased as letter eccentricity increased. In addition, a letter string type effect was found (F (2,73) = 4.9, p < 0.01). Reaction times for letters presented within un-connected letter strings were shorter than letters presented within connecting letter strings. The interaction between the factors was not significant (F (2,73) = 0.91, p = 0.401; Fig. 7, Table 6).

Table 6. Reaction times for letter type (connecting, un-connecting) as a function of letter position in letter-string (1, 2, 3, 4, and 5) according to the letter string type (connecting, un-connecting). Note: Error bars represent standard error.

<table>
<thead>
<tr>
<th>Letter String Type</th>
<th>Letter Position</th>
<th>SD</th>
<th>SD</th>
<th>SD</th>
<th>SD</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-connecting</td>
<td>Letter-1</td>
<td>448</td>
<td>101</td>
<td>469</td>
<td>106</td>
<td>481</td>
</tr>
<tr>
<td></td>
<td>Letter-2</td>
<td></td>
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Figure 7. Reaction times for letter type (connecting, un-connecting) as a function of letter position in letter-string (1, 2, 3, 4, and 5) according to the letter string type (connecting, un-connecting). Note: Error bars represent standard error.
6. GENERAL DISCUSSION

The critical finding from Experiments 1 and 2 was a symmetric drop-off in average letter visibility as the initial fixation position moved from the center of the stimulus to the periphery. These experiments replicated the well-known distance-from-fixation effects for letter identification (e.g., Estes et al., 1976; Nazir, Deutsch, Grainger, & Frost, 2000; Nazir et al., 1992). Recognition performance was mostly a function of distance from fixation. The shape of the letter visibility function varied substantially across the different fixation positions. There was one pattern of letter visibility that emerged as fixation position varied. Fixations on the central letter produced a visibility curve with a monotonic decline in performance for letters further along the string. When the middle of an ten-letter string was fixated upon, visibility dropped monotonically for letters further from fixation (Stevens & Grainger, 2003).

In addition, results from Experiments 1 and 2 appear to conform to prior reports of higher levels of letter visibility in the right visual field (Bouma, 1973; Kajii & Osaka, 2000; Nazir et al., 1992). Having the Arabic letters presented within a long string (11 letters) induced a specific processing bias that gave rise to superior visibility for letters presented in the right visual field. However, the effect of connecting/un-connecting letter position by visual eccentricity in Arabic was identical in RVF and LVF.

It is interesting to note that Nazir et al. (2000), in their study of Hebrew (a language read from right to left), found that letters to the right of a fixation were identified better than letters to the left of a fixation.

Results from the present study replicated the standard finding of a drop in performance with two flanking stimuli. The presence and the type of a letter string, affect letter identification. A letter presented within a connecting letter string (connecting flankers) showed even more interference than a letter presented within an un-connecting letter string (un-connecting flankers). This is in line with visual attentional accounts of crowding (Strasburger et al., 1991; Intriligator & Cavanagh, 2001; Strasburger, 2005) by which attentional deployment determines the extent of the crowding zone (Marzouki et al., 2013). The the type of flankers, as in the un-connecting letter string presentation conditions, would facilitate a focus of attention on the target letter since the inter-letter spacing enables better visual segregation (i.e., the target letter pops out). This is similar to the notion that different colored targets are thought to help focus attention (Scolari et al. 2007, Whitney & Levi,
However, the connecting letter string presentation has excessive feature integration (perceptual grouping) that decreases the target letter’s capacity to resist flanker interference (Desimone & Duncan, 1995). These findings are in line with prior studies showing that attracting visual attention to the target location can reduce crowding (Yeshurun & Rashal, 2010). One way to accommodate these influences of visual attention with an account of crowding in Arabic is via the type of letter string (connecting, un-connecting).

Since, sensitivity to statistical regularities of visual orthographic input emerges as a product of learning to read, effects of letter frequency were also observed in the performance of skilled readers on a low-level task. However, this does not explicitly activate lexical representations such as visual letter recognition or identification; this does assume that these tasks tap into the written word recognition system (Pitchford & Lefgeway, 2008). Since using letter strings instead of real words in tasks investigating letter identification minimizes the effects of top-down processes, the advantage of recognizing connecting Arabic letter types compared with un-connecting letter types, would suggest that this effect operates at, or modulates, a relatively early stage of visual orthographic processing (e.g., abstract letter encoding).

In sum, the present study investigated the influence of the presence and type of flanking elements, as well as target letter eccentricity, in a letter-in-string identification task. Results revealed a standard crowding effect in both connecting and un-connecting letter-string presentation conditions, with target letter identification being more difficult when target letters were surrounded by connecting flankers compared with a un-connecting flanker condition. Most importantly, connecting flankers caused a further decrement in performance in contradiction to Abdelhadi, Ibrahim, & Eviatar's (2011) findings that vowel detection in Arabic was better for letter strings containing connected letters than for those containing unconnected letters. This could be explained by the difference between the vowel detection task used by Abdelhadi, Ibrahim, & Eviatar (2011) and our letter detection task embedded in a letter string. Since in Arabic vowels appear above or below the letters, vowel detection is facilitated in connected letter string, while letter detection is inhibited when embedded in a connected letter string compared with unconnecting letter string as in the present study. Finally, the type of flanking stimulus (connecting, un-connecting) and the visual field (left, right) modulated flanker interference. Reading rates were worse for letter stimuli that had been embedded within a connecting letter string compared to an un-
connecting letter string; this is highlighted by inter-letter spacing relative to the letter’s eccentric placement across the letter string and visual field. We argue that the most parsimonious account of the present findings is related to visual Arabic letter connectedness, visual acuity, and crowding (flanker interference).

These results indicate that it might be possible to standardize reading rates across the visual field by compensating for reduced acuity, elevated crowding, and eccentric position to better equate the visibility of letters within words.

Additionally, we now have an empirically determined set of letter visibility measures as a function of letter type, letter string type, and possible fixation position in Arabic. These letter visibility results, in conjunction with various measures of lexical constraint, are useful for attempting to predict performance obtained with Arabic word stimuli while assessing the OVP and length effects.

The results of this study have important implications for current theories on encoding letter identity within written word recognition. Several specific, yet contrasting, models of letter position encoding have been proposed in recent years (see Davis, 2006; Schoonbaert & Grainger, 2004, for a detailed review). In some respects, our findings are most consistent with serial models of letter position encoding (e.g. Whitney, 2001). However, to be considered suitable for Arabic, models of letter recognition should take into account the present findings. This may involve modifying models such that the models incorporate: (i) the type of letters (connecting, un-connecting) by which processing Arabic orthography would benefit identification of connecting letters, (ii) the shape of letters (basic, initial, medial, and final), and (iii) the type of letter string.

7. SUMMARY AND CONCLUSIONS

The visual letter recognition is influenced by: (i) the letters' type (connecting, un-connecting), as connecting letters are easier to recognize than in-connecting letters; and (ii) letters' shape (basic, initial, medial, final), as medial and final are harder to recognize than basic and initial letter shapes, (iii) letter string's type, as reading rates were longer for letter stimuli that have been embedded within a connecting letter string compared to an un-connecting letter string with inter-letter spacing, (iv) visual field, as reading rates were longer for letter stimuli that have been presented in LVF compared to RVF, (v) eccentricity, as letter reading rates were correlated with its eccentric placement across the letter string.

The present study revealed a standard crowding effect in both connecting and un-connecting letter strings presentation conditions, with target letter identification
being harder when target letters were surrounded by connecting flankers compared with the un-connecting flanker condition. Most important, however, is that the connecting flankers caused a further decrement in performance. Finally, flanker interference was modulated by both the type of flanking stimulus (connecting, un-connecting) and the visual field (left, right). Reading rates are longer for letter stimuli that have been embedded within a connecting letter string compared to an un-connecting letter string with inter-letter spacing and relative to its eccentric placement across the letter string and the visual field.

We argue that the most parsimonious account of the complete set of findings is in terms of visual Arabic letters connectedness, visual acuity, plus the crowding (flanker interference). Practically, these results indicate that it might be possible to standardize reading rates across the visual field by compensating for reduced acuity, elevated crowding, and eccentric position to better equate the visibility of letters within words. Theoretically, the results of this study have important implications for current theories on encoding letter identity within written word recognition. However, since there are universal processes in reading and writing-system specific processes (Perfetti, Cao, & Booth, 2013), in the letter level our findings are most consistent with serial models of letter position encoding (e.g. Whitney, 2001) while in the word level our findings are most consistent with the dual route model.

ACKNOWLEDGMENT

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