The Effect of expertise and biscriptalism on letter perception: The complexity benefit

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Abstract

Previous work has demonstrated that the visual complexity of letter-shapes is processed differently by naïve and expert observers. Specifically, fluent readers of the Arabic alphabet were found to discriminate complex letters more readily than less complex letters, whereas naïve observers exhibited the opposite effect. This "complexity benefit", wherein complex letters confer a processing advantage to expert observers, is not yet well understood. In a new study, we investigate whether this effect generalizes across scripts, and whether it is unique to individuals with biscriptal experience (knowledge of reading two different scripts). The results of the three experiments confirm that the complexity benefit is characteristic of expert monoscriptal and biscriptal readers, and that, furthermore, there may be a biscriptal advantage in processing visual complexity.

Keywords: biscriptal; orthography; visual complexity; perceptual expertise

Background

Letter perception and identification require detection and processing of a letter's component visual features (Grainger, Rey, & Dufau, 2008). For example, Pelli and colleagues (Pelli, Burns, Farell, & Moore-Page, 2006) determined that letters are identified by detecting 7 ± 2 visual features. While core properties of the human visual system certainly determine how and which visual features are detected for in letter identification, there is increasing evidence that the extent and type of experience with letters influences how the visual system processes them.

Wiley, Wilson, & Rapp (2016) examined the effects of both alphabet and expertise on Arabic letter perception by comparing same/different letter judgments of expert, biscriptal Arabic-English readers, and naïve, monoscriptal English-only readers. Among the findings was that letter complexity, defined as the number of visual features in a letter[1], was associated with slower/less accurate responses for naïve observers, but faster/more accurate responses for expert, biscriptal readers. This finding suggests that extensive experience leads to more efficient visual processing of complex shapes. In other words, whereas for naïve observers, complex letter-shapes are more difficult to discriminate than are simple ones, for expert observers the reverse is true. This effect was referred to as the "complexity benefit". As a first step to furthering our understanding of the complexity benefit, the current study seeks to determine (a) whether the complexity effect is specific to Arabic, and (b) whether the magnitude of the effect is related to the amount of experience with a specific script or if extends across scripts.

The Current Study

Whereas Wiley, Wilson, & Rapp (2016) focused only on comparing the effects in letter perception of the amount of expertise (naïve or expert observers), it is also the case that those participants can be divided along another dimension: monoscriptal and biscriptal. Here, we make use of the biscriptal experience to better understand the nature of the complexity benefit. Specifically, we address two questions:

Question 1: Is the complexity benefit limited to Arabic letters?

Question 2: Is the complexity benefit affected by the amount of expertise with a script?

Question 3: Does biscriptalism affect the perception of Roman letters?

The answers to these questions have implications for our understanding of whether and how the visual system is affected by extensive reading experience. There are at least two relevant hypotheses that are evaluated: (1) the complexity benefit is a consequence of extensive experience with letter identification within a specific set (e.g. the Roman alphabet). In that case, expertise with one script should have no bearing on the visual processing of another. (2) The complexity benefit may be related to the manner in which visual features are processed, regardless of the letter in which they appear; in this case, expertise with one script may influence the processing of another, depending on the extent to which they make use of similar sets of visual

[1] An alternative definition of complexity, perimeter squared over ink area, has been used successfully by Pelli, Burns, Farell, & Moore-page (2006) to account for human efficiency in letter identification. However, it was found that this measure of complexity was a significantly weaker predictor of RT in the same/different judgment, as originally reported in Wiley, Wilson, & Rapp (2016).

features. This latter possibility would support a "biscriptal advantage", such that biscriptal Arabic-English readers should show a greater complexity benefit than monoscriptal readers. In addressing these questions, we also determine whether or not our original finding of a "complexity benefit" is replicable, whether or not it is an artifact of the Arabic alphabet, and whether or not it is true of monoscriptal as well as biscriptal individuals.

The questions are addressed in three experiments. In Experiment 1, the experimental protocol from Wiley, Wilson, & Rapp (2016) was used with a considerably larger sample size of monoscriptal Roman-only readers, with implementation in Amazon's Mechanical Turk, with both Arabic and Roman letters. This experiment directly tests whether the complexity benefit is unique to the Arabic alphabet, or whether it is also present in monoscriptal participants viewing the Roman alphabet.

Experiment 2 is a re-analysis of the data from Wiley, Wilson, & Rapp (2016), specifically the reaction time measurements from the same-different judgment task with pairs of Arabic letters. We separate the expert, biscriptal participants into two groups, one low-proficiency and the other high-proficiency, to shed light on whether the amount of expertise with reading a script affects the magnitude of the complexity benefit.

Finally, in Experiment 3 we use the same protocol as in Experiment 2 with new samples of both monoscriptal (Roman-only) and biscriptal (Arabic & Roman) participants, viewing both Arabic and Roman letters. This experiment allows us to address whether expertise with reading one script affects the perception of a second script, specifically evaluating whether or not being biscriptal provides an advantage in terms of the complexity benefit.

Experiment 1: Is the complexity benefit limited to Arabic letters?

Following Wiley, Wilson, & Rapp (2016): we used a same-different judgment task with pairs of letters, using letter-shapes from both the Arabic and Roman alphabet. For all experiments, the questions of interest are addressed on the basis of reaction times (RT, on correct trials), analyzed using linear mixed-effects modeling (LMEM; including random intercepts and slopes by both participants and items).

Participants

167 participants were recruited online via Amazon's Mechanical Turk (MTurk), receiving payment of $7.50/hour for their participation. 86 participants completed the task with Arabic letters and 81 with Roman letters. All participants reported no knowledge of any language written in a non-Roman script, and thus all are considered monoscriptal (MS).

Stimuli

A set of 23 letter-shapes from the Arabic alphabet was presented in Adobe Arabic, in font size 24 (stimuli subtended 0.17°-0.31° and 0.05°-0.35° of visual angle, respectively in the vertical and horizontal dimensions). A set of 23 letter-shapes from the Roman alphabet was also presented in Arial, font size 16, thereby equating the size range of the two alphabets.

Both sets of stimuli included 8 pairs of allographs (i.e. 8 letters were presented with two letter-shapes, such as "A" and "a"; see Table 2). The stimuli are listed in Tables 1 and 2.

Procedure

Each trial began with a central fixation cross (250ms), which disappeared and was replaced by a pair of letters simultaneously on either side of fixation, 48 pixels apart. Each pair of letters was presented for 2000ms or until a response of "same" or "different" (by pressing either the "a" or "l" key on the keyboard was recorded. After a response or two-second timeout there was a 500ms intertrial blank screen. Participants completed either the task in Arabic or in Roman letters but not both; the ratio of same to different trials was 40/60, for a total of 437 trials.

Analysis

Using only correct responses, a single LMEM was fit to the "same" pairs[2] data to determine the effect of complexity (number of visual features from a list of 14) on reaction time, and whether this effect differed across groups. The regression model was fit using R (R Core Team, 2015), package *lme4* (Bates, Mächler, Bolker, & Walker, 2015), and confidence intervals for the parameters of interest were determined using parametric bootstrapping; plots are provided based on the R package *effects* (Fox, 2003).

Regression predictors: For the fixed effects, two predictors of interest were included: the categorical variable Alphabet (Arabic or Roman, with sum-coding) and the continuous variable Complexity (total number of visual features, ranging from 4-12). Two additional predictors were included as control variables: Trial Order and Previous RT (reaction time on the preceding trial), to control for trends in RT across the duration of the experiment. Finally, we included the interaction Alphabet X Complexity.

The following crossed random effects were included: random intercepts were included both by participants and by items, as was a random slope for the effect of Complexity by participant.

[2] Only the "same" pairs are used here because they are used to measure the effects of visual complexity. The "different" pairs are discussed in detail in Wiley, Wilson, & Rapp (2016), where they were used to determine the relative importance of various visual features (e.g. lines, curves) for letter perception and how that relative importance differed between naïve and expert observers.

Results

The results are reported in Figure 1. Confidence intervals are based on 1,000 bootstrap simulations.

The estimated complexity benefit is significant for Roman letters, beta = -0.014 [-0.017, -0.010], whereas there is a significant increased RT as the number of features increases for the Arabic alphabet, beta = 0.005 [0.002, 0.009]. The interaction between alphabets is significant, a beta difference = 0.019 [0.015, 0.024].

Summary: The finding that the complexity benefit also exists for monoscriptal participants in the Roman alphabet (in which they are experts) is replicated in a large MTurk sample, as is the finding that the opposite effect (slower RT on more complex letters) for monoscriptal observers with no experience in reading Arabic.

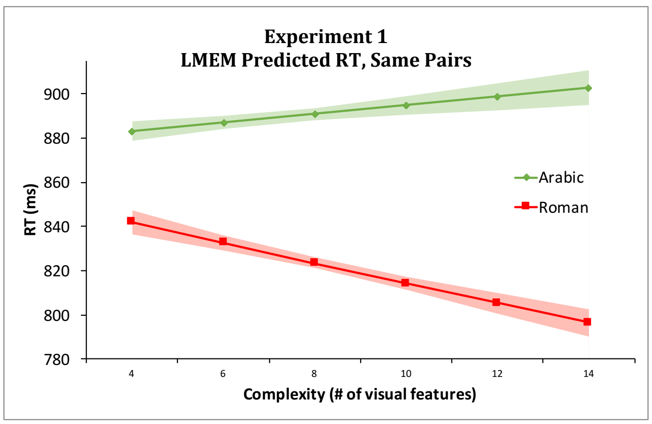

Figure 1: Experiment 1, predicted RT (ms) as a function of complexity (# of visual features) in the Arabic (green) and Roman (red) alphabets, measured in response to "same" pairs.

Experiment 2: Is the complexity benefit affected by amount of expertise?

Experiment 2 is a reanalysis of data originally presented in Wiley, Wilson, & Rapp (2016). The procedure was the same as that described for Experiment 1, with the following differences in participants and stimuli.

Participants

There were 34 participants, all from the Johns Hopkins University community, who took part in two one-hour sessions, receiving either course credit or $20 for their participation. The participants were organized into three groups:

Low-proficiency biscriptal (L-BS, n = 11): individuals whose first written language is English and who have had 2-3 years of studying Arabic.

High-proficiency biscriptal (H-BS, n = 11): individuals who learned to read and write Arabic simultaneously with English, or as a second language with at least 4 years of study.

Monoscriptal (MS, n = 12): consists of participants whose first language is English, and who have had no exposure to reading or writing in non-Roman scripts[3].

Stimuli

The stimuli were a superset of the Arabic letters used in Experiment 1, for a total of 45 shapes. However only the 23 stimuli used for Experiment 1 are analyzed here in order to better compare results across experiments.

Procedure

Stimuli were presented using E-Prime 2.0 (Psychology Software Tools, Pittsburg, PA). Participants completed the experiment over two sessions, with each session consisting of 990 trials with a 50/50 ratio of 50/50 same to different trials. For this analysis, a total of 506 trials were used.

Analysis

The same analysis was used as in Experiment 1.

Regression predictors: The model structure was the same as outlined in Experiment 1 except that the predictor Alphabet replaced by the predictor Group (MS, L-BS, or H-BS, with sum-coding).

Table 1: Arabic letter-shapes and their complexity, the mean RTs across Experiments 2 and 3, for each group for each letter, and the correlation between complexity and mean RT (bottom row).

Letter	Complexity	MS	L-BS	H-BS
ط	10	563	549	622
ح	7	583	567	666
ا	4	567	536	625
ع	10	575	557	639
ـعـ	10	573	560	648
ـع	10	591	593	702
بـ	7	556	569	605
ذ	6	579	582	668
ظ	11	609	586	617
غ	11	604	579	608
ه	6	557	559	614
ـه	8	572	558	619
ج	8	607	578	631
ك	6	606	573	616
كـ	6	567	552	611
ل	5	552	554	588
لـ	4	603	568	668
ن	7	587	571	610
نـ	4	573	613	709
ر	4	562	571	605
س	12	579	566	593
سـ	9	576	581	634
ز	5	577	570	645
r =		0.298	0.071	-0.148

[3] The monoscriptal participants had varying degrees of knowledge of languages written in the Roman alphabet other than English, primarily Spanish or French.

Results

The re-analysis of data from Wiley, Wilson, and Rapp (2016) is reported in Figure 2 based on the LMEM as previously described; confidence intervals are based on 1000 bootstrap simulations.

The estimated beta-weight for the effect of Complexity is for the MS group = 0.015, 95% CI [0.010, 0.020] Thus, we again find that among the naïve (monoscriptal) participants more complex letters lead to significantly slower reaction times.

For the biscriptal groups, for the L-BS the effect is estimated = -0.002 [-0.008, 0.002]; and for the H-BS = -0.007 [-0.013, -0.001]. Thus, only the H-BS show a significant complexity benefit, while the L-BS show only a trend toward faster RT on more complex letters.

The estimated difference between the MS and L-BS is = 0.017 [0.011, 0.024], and between the MS and H-BS = 0.022 [0.014, 0.029]. Both biscriptal groups show significantly more negative (hence, more of a complexity benefit) than the monoscriptal group. The estimated difference between the two biscriptal groups = 0.005 [-0.003, 0.011], with a nonsignificant trend toward a greater complexity benefit for the H-BS relative to the L-BS.

Summary: Both biscriptal groups show a numerically larger complexity benefit than the monoscriptal group; although only for the H-BS group is the complexity benefit statistically significant.

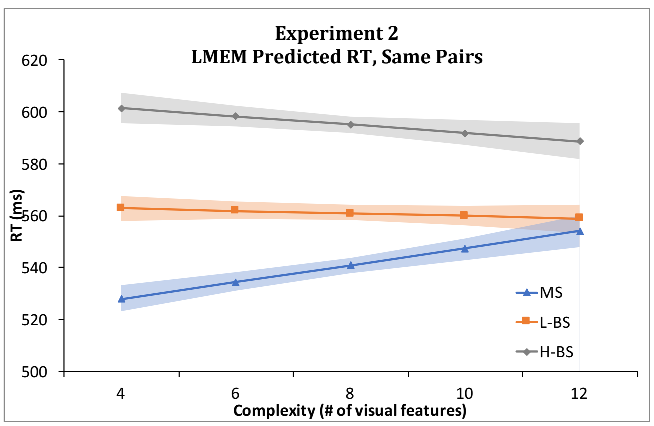

Figure 2: Experiment 2, Predicted RT (ms) as a function of complexity (# of visual features) in the Arabic alphabet, measured for each group of participants in response to "same" pairs.

Experiment 3: Does biscriptalism affect the perception of Roman letters?

The same procedure as outlined in Experiment 1 was used, with a few differences noted as follows.

Participants

29 students from Johns Hopkins University (ages 18-22), all different from those in Experiment 2, took part in the one-hour experiment, receiving either course credit or $10 for their participation. The participants were divided into L-BS (n = 7), H-BS (n = 5), and MS (n = 17) for a total of 29 participants.

Stimuli

The stimuli were identical to those used in Experiment 1.

Procedure

The same procedure as Experiment 1 was used, except participants completed the task for both alphabets separately across two sessions, with the order (Arabic-Roman or Roman-Arabic) counterbalanced across participants.

Analysis

The same analysis as described for Experiment 1 was conducted, plus the addition of the variable Group (MS, L-BS, or H-BS, sum-coded) and the 3-way interactions of Alphabet X Group X Complexity and Alphabet X Group X Previous RT. The random effects structure was the same as in Experiment 1, with the addition of (correlated) random slopes for the effect of Alphabet by participants.

Table 2: Roman letter-shapes and their complexity, the mean RT from Experiment 3, for each group for each letter, and the correlation between complexity and mean RT (bottom row).

Letter	Complexity	MS	L-BS	H-BS
a	10	532	506	605
A	10	507	497	563
b	8	528	553	613
B	14	518	527	595
C	6	545	530	627
d	8	519	541	658
D	7	512	510	593
E	12	520	542	584
g	9	516	536	626
G	7	530	537	612
I	5	547	552	648
j	5	529	539	631
J	4	526	519	646
O	5	522	545	628
q	9	523	538	657
Q	9	517	531	593
r	6	529	540	658
R	10	519	519	623
S	7	528	520	600
t	9	538	543	643
T	8	523	522	585
W	11	533	528	642
X	8	546	544	619
	r =	-0.353	-0.231	-0.424

Results

The results from participants completing the same-different task with both alphabets are reported in Figure 3 (Arabic) and Figure 4 (Roman). Confidence intervals are based on 1,000 bootstrap simulations.

For the Arabic alphabet, the MS show significantly slower RTs on more complex letters, beta estimated = 0.013

[0.007, 0.017]. The L-BS show a nonsignificant trend in the same direction, beta = 0.007 [-0.001, 0.014], whereas the H-BS show a nonsignificant trend toward a complexity benefit, beta = -0.007 [-0.018, 0.001].

While the complexity benefit is not significant within either biscriptal group, the difference between the H-BS both of the other two groups is significant: the H-BS beta-weight is significantly different than that for the MS, by an estimated 0.019 [0.009, 0.031] and than the L-BS by beta = 0.014 [0.003, 0.025]. The difference between the MS and L-BS is not significant (beta = 0.006 [-0.003, 0.014]).

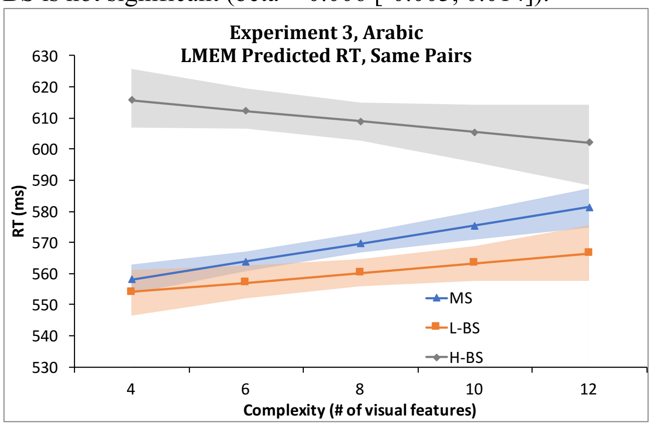

Figure 3: Experiment 3, predicted RT (ms) as a function of complexity (# of visual features) in the Arabic alphabet, measured for each group of participants in response to "same" pairs.

For the Roman alphabet, the MS show a significant complexity benefit = -0.005 [-0.010, -0.0002]. The L-BS show a marginally significant complexity benefit, beta = -0.008 [-0.016, 0.0001]. The H-BS show a significant complexity benefit, beta = -0.020 [-0.029, -0.013].

Finally, the H-BS show a significantly greater effect than both the MS (beta = 0.015 [0.005, 0.026]) and the L-BS (beta = 0.013 [0.002, 0.025]). There is no difference between the MS and the L-BS (beta = 0.002 [-0.006, 0.011]).

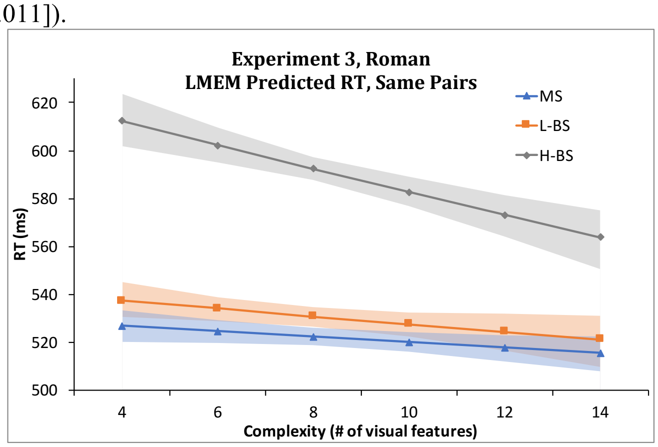

Figure 4: Experiment 3, Predicted RT (ms) as a function of complexity (# of visual features) in the Roman alphabet, measured for each group of participants in response to "same" pairs.

Summary: We find a similar pattern of results for the Arabic alphabet as in Experiment 2 with the H-BS group showing a significantly greater complexity benefit than either then MS or the L-BS groups. Critically, a complexity benefit is found for the Roman alphabet for all groups, including the monoscriptal (English-only) participants, indicating that it is not an artifact of the Arabic alphabet or of being biscriptal. The magnitude of the effect is significantly greater in the H-BS than in either the MS or L-BS groups, suggesting a possible biscriptal advantage.

Discussion

We investigated the role that expertise and biscriptalism play in the visual processing of letter-shapes. Specifically, we sought to determine whether: (1) the complexity benefit, wherein expert readers of a script identify complex letters significantly more quickly than simpler letters, occurs for scripts other than Arabic where it was first reported, (2) the complexity benefit is limited to biscriptal individuals or is present also in monoscriptals, and (3) there is a biscriptal advantage for visual processing of letters, such that biscriptals show a greater complexity advantage or if, instead, the magnitude of the complexity benefit is simply tied to the amount of experience with a script. There were three participant groups: monoscriptal, English-only readers (MS), and two biscriptal Arabic-English reader groups, one with four or more years of experience (H-BS) and one with two or three years (L-BS). We used LMEM to determine the direction and strength of the relationship between letter complexity (as defined by the number of visual features), and whether this relationship differs across groups of participants and across alphabets.

The results of Experiments 1 and 3 both reveal that the complexity benefit is not an artifact of the Arabic alphabet. Monoscriptal participants who participated in the laboratory or the MTurk experiments all exhibited a complexity benefit when performing the same-different task with Roman letter stimuli. Thus, it would seem that the complexity benefit is not only a general trait of reading expertise, but also is not unique to individuals with biscriptal experience.

Additionally, the results of Experiments 2 and 3 provide further details regarding the complexity benefit phenomenon. While a significant complexity benefit was not limited to biscriptal individuals, the effect was greatest in the high-proficiency biscriptal individuals. This group showed a larger complexity benefit than the other two groups in both Arabic and Roman scripts. This is particularly interesting, given that the monoscriptal and biscriptal participants presumably had comparable expertise with the Roman alphabet. In fact, if anything the monoscriptal participants are likely to have had *more* experience with the Roman alphabet, as the biscriptal participants would have spent some of their time reading in Arabic instead of Roman letters. It is possible that this division of reading time between the two scripts may underlie the overall slower reaction times exhibited by this group, analogous to the rationale provided for some of the findings in the literature on spoken word production with bilinguals (Gollan et al., 2008). This possibility will require more targeted experimental work. Nonetheless, the larger complexity benefit observed for the high expertise biscriptal participants indicates that there may be a biscriptal advantage for processing visual complexity, at least for letters.

The mechanism underlying the complexity benefit itself is not yet well understood. There are multiple possible explanations for why expert observers learn to identify more complex letters more quickly or accurately. One possibility is that expertise leads to the creation of *new* visual features— such that features are "bundled" together, making a complex letter no longer complex. For example, the letter "w" may not be processed as four slanted lines, three intersections, two terminations, with symmetry and cyclicity, but instead as fewer features or even a single feature, "w". This type of expertise effect is consistent with findings in perceptual learning research (e.g. Goldstone, 1998; Kellman & Garrigan, 2009; Sireteanu & Rettenbach, 2000).

Another explanation for the complexity benefit is that it is related to the distinctiveness of letter-shapes within the set of shapes being processed. Under such an account, a complex letter like "w" may be easier to identify because its greater number of features provide more possible ways to distinguish it from other letters. This is compatible with findings from visual crowding effects, indicating that a target is easier to identify within an array of distractors if it is relatively more complex than those distractors (Bernard & Chung, 2011; Chanceaux, Mathôt, & Grainger, 2014). Accordingly, with increasing expertise, one learns not only the visual properties of each of the letters, but the distribution of features across the *set* of letters.

Relatedly, it may be that experts learn a greater number of ways to identify complex letters relative to simpler letters, allowing the identification process to terminate sooner. For example, whereas an observer with minimal experience may identify "w" only after considering all of its features, an expert may identify it as soon as some distinct combination of features (a subset of the total number of features) are recognized. In this case, a "simple" letter such as 'l' may be more difficult to distinguish from other letters, because while a complex letter like "w" can be identified without full consideration of all of its features and without searching for the absence of certain features, an "l" does not afford these opportunities.

Of these possibilities, perhaps the one most consistent with a biscriptal advantage would be the creation of new complex features from simpler features—biscriptal individuals' expertise with a wider range of letter-shapes may result in a larger feature 'vocabulary' that allows relatively more complex shapes to be more readily processed. In future research, it will be important to examine if the biscriptal complexity advantage extends to other types of visual stimuli, and to identify evidence to adjudicate between possible mechanisms that support the complexity benefit.

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References

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67, 1–48.

Bernard, J.-B., & Chung, S. T. L. (2011). The dependence of crowding on flanker complexity and target-flanker similarity. Journal of Vision, 11(8), 1–1.

Chanceaux, M., Mathot, S., & Grainger, J. (2014). Effects of number, complexity, and familiarity of flankers on crowded letter identification. Journal of Vision, 14(6), 7–7.

Fox, J., & Hong, J. (2009). Effect Displays in R for Multinomial and Proportional-Odds Logit Models: Extensions to the effects Package. Journal of Statistical Software, 32(1), 1-24.

Goldstone, R. L. (1998). Perceptual learning. Annual Review of Psychology, 49(1), 585–612.

Gollan, T., Montoya, R., Cera, C., & Sandoval, T. (2008). More use almost always means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. Journal of Memory and Language, 58(3), 787-814.

Grainger, J., Rey, A., & Dufau, S. (2008). Letter perception: from pixels to pandemonium. Trends in Cognitive Sciences, 12(10), 381–387.

Kellman, P. J., & Garrigan, P. (2009). Perceptual learning and human expertise. Physics of Life Reviews, 6(2), 53–84.

Palmer, S. E. (1999). Vision science: Photons to phenomenology (Vol. 1). Cambridge, MA: MIT Press.

Pelli, D. G., Burns, C. W., Farell, B., & Moore-Page, D. C. (2006). Feature detection and letter identification. Vision Research, 46(28), 4646–4674.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sireteanu, R., & Rettenbach, R. (2000). Perceptual learning in visual search generalizes over tasks, locations, and eyes. Vision Research, 40, 2925–2949.

Wiley, R. W., Wilson, C., & Rapp, B. (2016). The Effects of Alphabet and Expertise on Letter Perception. *Journal of Experimental Psychology: Human Perception and Performance, 42*(8), 1186-1203.