# Reading direction is sufficient to account for the optimal viewing position in reading: The case of music reading

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**Abstract**

The Optimal viewing position (OVP), the position where word recognition is the best, is biased to the left for English words. Several explanations have been proposed to account for this phenomenon, including the left hemispheric dominance for language, asymmetric information structure of words, and reading direction. However, it is unclear which factor(s) is necessary or sufficient to cause an asymmetric OVP. Using music reading, which shares only the reading direction but not the other two factors with word reading, we show that the OVP for three-note sequences is significantly biased to the left only for expert readers but not for novices. The degree of asymmetry in the OVP curve for music readers increases with individual reading skill, suggesting that their OVP is gradually shifted to the left during the development of reading skills. These suggest that habitual reading direction is sufficient to account for a biased OVP to the left.

**Keywords:** optimal viewing position, word reading, music, expertise, visuospatial bias

## Introduction

It has been well documented that where we look within a word or a sentence determines our reading performance. For example, we recognize English words the best when we fixate to the left of the middle of the words, i.e., the optimal viewing position (OVP) for English words is on the left (also called 'convenient viewing position'; O'Regan, 1984; Brysbaert & Nazir, 2005). This cannot be explained by the acuity function of our eyes, which is the highest at the fovea but drops symmetrically in the left and right visual periphery (Bouma, 1970). Why is the OVP for English word asymmetric and biased to the left, but not to the right?

Multiple factors have been proposed to account for this phenomenon. The first factor is related to the cerebral hemispheric dominance for language processing (Brysbaert & Nazir, 2005). When we fixate at the left part of a word, most of the letters falls onto the right visual field, where information is initially projected to the left hemisphere. As the language center for most people is in the left hemisphere, word recognition is more efficient when we fixate at the left part of a word as compared with when we fixate at the right part of a word (where most of the word falls onto the left visual field and is initially projected to the right hemisphere). Supporting this account, individuals with right-hemisphere-dominant language functions have a shifted OVP more towards the end of a word compared with the left-hemisphere-dominant individuals (Brysbaert, 1994; Hunter et al., 2007).

Second, the OVP for words is affected by the information structure of the words. For example, the OVP shifts to the informative position of the words in terms of word identity or meaning, both when the informative part is at the word beginning (e.g., the left part of an English word) or at the end (e.g., the right part of an English word; O'Regan et al., 1984; Deustch & Rayner, 1999). Also, adding a prefix shifts the OVP towards the word end while a suffix shifts the OVP towards the word beginning (Farid & Grainger, 1996). Since the initial letters are in general more informative about the identity of the word than the last letters for English, the OVP for English words is on the left (Brysbaert & Nazir, 2005; Farid & Grainger, 1996).

Third, the OVP for words can be explained by reading direction. In left-to-right scripts, since the newly arriving information and the next eye movement is on the right, attention is directed more to the right visual field. With years of reading training, perceptual span for reading (the region around fixation from which useful information is extracted) extends further to the right compared with the left (Deutsch & Rayner, 1999). The OVP for English words is on the left because a left fixation leaves most of the word in the right visual field where English readers learn to recognize the word better (Brysbaert & Nazir, 2005). Prior work shows that the OVP for right-to-left scripts (e.g. Arabic) have a more symmetrical OVP (Farid & Grainger, 1996).

While many factors can modulate the OVP for words, which one(s) is necessary and/or sufficient for an asymmetric OVP to occur? In word reading, it is impossible to isolate and test the effect of each factor. Here, we tested whether reading direction alone is sufficient to lead to a left-biased OVP with the domain of music reading. While music reading shares the left-to-right reading direction with English reading, it does not involve strong hemispheric lateralization as experts learn to recruit both hemispheres for music reading (Wong & Gauthier, 2010). In addition, music notation does not follow as strict morphological/

orthographical rules as English text does. Therefore it is unlikely that music sequences in general have an asymmetric information distribution as that in English words[1]. Therefore, music reading allows us to test whether reading direction is sufficient to cause a left-biased OVP.

Here we used three-note sequences and single notes (i.e., the shortest note sequences) as our stimuli. A sequential matching task which did not require music knowledge was used so that we were able to measure the OVP in both experts and novices. In addition, we took advantage of the wide range of music reading ability among the participants to examine how the OVP changes with reading skills. We hypothesized that the OVP is gradually shifted to the left (for left-to-right scripts) when one's reading skill improves. To test this hypothesis, we examined the relationship between the degree of asymmetry of the OVP curve and individual music reading fluency. The hypothesis predicts that the degree of asymmetry of the OVP curve should increase with individual reading fluency.

## Methods

### Participants

Forty-two participants completed the experiment for cash payment or course credits. All participants were right-handed (according to the Edinburgh Handedness Inventory; Oldfield, 1971) except three participants (one intermediate and two novice readers) who were subsequently excluded from data analysis. Twenty-six participants had been formally trained in music reading and were further divided into the expert and intermediate group according to their performance in the perceptual fluency test (see below). The thirteen experts included 12 females and 1 male ($M_{age}$ = 20.2, s.d. = 1.69) with 13.4 years of music reading experience on average (ranging from 10-20 years). The twelve intermediate readers included 11 females and 2 males ($M_{age}$ = 21.8, s.d. = 4.36) with 9.3 years of experience reading music on average (ranging from 2-17 years). The thirteen novices reported that they could not read music, with 8 females and 5 males ($M_{age}$ = 22.4, s.d. = 5.42) and 0.31 years of music reading experience (ranging from 0-3 years). All reported normal or corrected-to-normal vision and gave informed consent according to the guidelines of the Ethics Committee of the University of Hong Kong.

### Stimuli and Design

The experiment was conducted on PCs with the Eyelink 1000 eyetracker (SR Research Ltd, Canada), and Matlab using the Psychtoolbox and the Eyelink Toolbox extension. The eyetracker was positioned on the desk and sampled pupil location at 500 Hz. The tracking mode was pupil and corneal reflection. The standard nine-point calibration procedure was administered at the beginning of the task; the procedure was repeated whenever the drift correction error was larger than one degree of visual angle during the experiment. The acceleration threshold was 8000 degree/s$^2$ and the threshold for saccade velocity was 30 degree/s. Participants viewed the stimuli at 62 cm from the monitor using a chin rest.

The stimuli were generated with Matlab. 400 three-note sequences were randomly generated, with the constraint that there were no repeated notes within each sequence and no repeated sequences within the set. The sequences subtended about 3º x 3º. Each sequence was paired with a distractor sequence, in which one of the notes was shifted for one step up or down (counterbalanced). Single notes included 11 quarter notes from the note below the bottom staff line (D4) to the note above the top line (G5). They subtended about 1.6º x 3.2º in visual angle. The contrast of the single note stimuli was reduced to half to avoid ceiling performance. The distractor of each single note was the note either one step up or down (counterbalanced).

A sequential matching task was used (Figure 1a). Each trial started when a central fixation was confirmed by the eyetracker. Then, a target stimulus was presented (for 600 ms for sequences and 80 ms for single notes) while participants maintained a central fixation. If the eyetracker detected an eye fixation away from the center, the trial was aborted and an error message was presented to the participant. Next, a second stimulus was presented in the upper or lower visual field at 3.6º from the central fixation. Participants were instructed to saccade to this image and judged whether the two stimuli were identical or not by key press as fast and as accurately as possible.

The critical manipulation was the position of the first target stimulus such that participants fixated at different viewing positions. For sequences, the target was presented at 2º left, 1º left, 0º, 1º right, or 2º right from the central fixation such that participants' central fixation fell onto the far-right, right, center, left, or far-left part of the sequences respectively (Figure 1b). For single notes, the target was presented at 2.5º left, 0º or 2.5º right from fixation. The

[1] There is no consensus and no formal study (to our best knowledge) on the information structure of music sequences. However, probable combinations of sequences (e.g. melodies) are defined by specific music pieces without general morphological, orthographical or phonological structure applicable to all pieces. In this experiment, no musical context, key signatures or accidentals (e.g. sharps or flats) were provided and the sequences only varied along the most common C major scale. In this case, all combinations of the notes are highly probable such that the notes are unlikely more predictable by the left or right part of the sequences. Although some pitch pairs may be more frequent than others in general (e.g. tonal pitch pairs such as 'C' and 'E' are used more frequently compared with tritone pairs such as 'C' and 'F#'), such predictiveness of tone pairs should be largely symmetrical (e.g. 'C' is unlikely followed by 'F#', and 'F#' is also unlikely followed by 'C'). As a result, there is presumably no information structure biased to the left or right for music sequences, at least under the current context.

dependent measure was the sensitivity (d') and response time (RT).

Trials with different fixation positions were randomized. For sequences, there were 400 trials with 80 trials for each fixation position. For single notes, there were 180 trials with 60 trials for each fixation position. Participants were tested with single notes before the sequences. For each type of stimulus, 20 practice trials with feedback were provided before testing (without feedback).

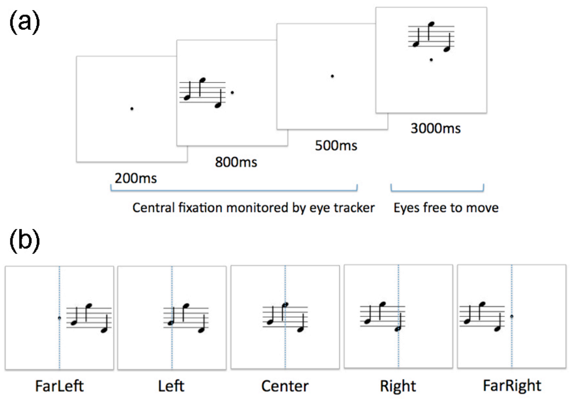


Figure 1. The sequential matching task (a) and the five fixation positions relative to the note sequences (b). Participants kept central fixation indicated by the black dot. The blue line was marked for illustration purposes and was not actually presented during the test.

## Measure of perceptual fluency

We assessed fluency in music reading with a sequential matching paradigm and used this as an indicator of individual music reading ability since it is more direct and objective compared with other measures such as years of experience and self-rated ability (Wong & Gauthier, 2010). On each trial, a central fixation was presented for 200 ms, followed by a 500 ms pre-mask, and a four-note sequence for a varied duration. After a 500 ms post-mask, two four-note sequences appeared side-by-side, one identical to the first sequence, and the other with one of the notes shifted by one step (with up/down shifts counterbalanced). The task was to select the matching sequence by key press. The presentation duration threshold for 80% accuracy was estimated four times, each with 40 trials, using the QUEST algorithm (Watson & Pelli, 1983). Sequences were randomly generated using notes ranging from the note below the bottom line (a 'D' note) to the note above the top line (a 'G' note). Contrast for all the stimuli was lowered by about 60% to avoid a ceiling effect.

To control for individual differences not specifically tied to expertise with notes, perceptual fluency for four-letter strings was measured in an identical procedure. The strings were randomly generated with 11 letters: b, d, f, g, h, j, k, p, q, t, and y. These letters were selected because they contain parts extending upward or downward, similar to musical notation. To create distractor strings, one of the four letters was selected (counterbalanced across stimuli) and replaced by a different letter randomly drawn from the set. The string was shown at the same lowered contrast as the sequences.

# Results

One novice and one intermediate reader were excluded from data analyses because their perceptual fluency for notes was > 3 s.d. away from the mean of the rest of the group. Therefore, thirteen experts, twelve intermediate and twelve novice readers were included.

## OVP for sequences

We observed a left-biased OVP for note sequences in experts, which was not found in the other two groups. A 3 x 5 ANOVA with Group (Experts, Intermediates, Novices) and Fixation Position (Far Left, Left, Center, Right, Far Right) on d' revealed a significant main effect of Group, $F(2, 34) = 10.2$, $p = .0003$, in which experts performed better than the other groups in general (LSD tests, $p < .05$). A main effect of Fixation Position was significant, $F(4, 136) = 18.8$, $p \leq .0001$, which marginally interacted with Group, $F(8, 136) = 1.89$, $p = .066$ (Figure 2a).

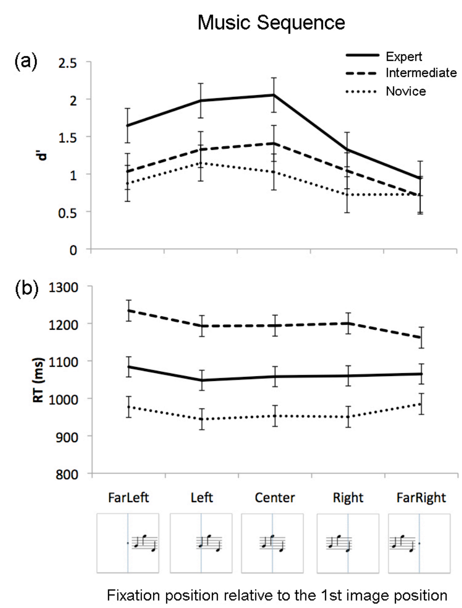


Figure 2. Matching performance for three-note sequences in d' (a) or RT (b) with different fixation positions relative to the first presented images.

To increase statistical power, we limited our analyses within the expert and novice groups, as the OVP function for intermediate readers was similar to the other two groups (Figure 2a). Results were similar to the above, except that the Group x Fixation Position interaction reached significance, $F(4,92) = 3.47$, $p = .011$. Sheffé tests ($p < .05$) revealed that d' was similar across positions for novices, suggesting that none of the viewing positions was 'optimal'. For experts, in contrast, d' was similar between the Far Left, Left and Center positions, while d' for the Center position was better than the Right and Far Right positions. Importantly, d’ for the Left position was better than the Right, and that for the Far Left position was better than the Far Right, suggesting the OVP for three-note sequences was biased to the left for experts.

Within the intermediate readers, we did not observe any clear pattern for the OVP function. A one-way ANOVA with Fixation Position on d’ was significant, $F(4,44) = 4.69$, $p = .003$. Sheffé tests ($p < .05$) revealed that d’ at the Center position was better than the Far Right but no different from the Far Left. However, d’ was similar between Left and Right positions, and between Far Left and Far Right positions. Therefore we could not conclude that the OVP function for the intermediate readers was biased to either side of the sequences.

For RT, the 3 x 5 ANOVA with Group (Experts, Intermediates, Novices) and Fixation Position revealed a main effect of Group, $F(2, 34) = 7.36$, $p = .002$, in which intermediate readers responded significantly slower than the other two groups (LSD tests, $p < .05$; Figure 2b). A main effect of Fixation Position was significant, $F(4, 136) = 3.08$, $p = .018$, in which performance at the Far Left position was slower than the Left in general (Sheffé tests, $p < .05$). The interaction between Group and Fixation Position did not reach significance ($p > .2$). When the intermediate readers were excluded, only the main effect of Fixation Position was significant in a similar manner as the above.

## OVP for single notes

A left OVP was observed in intermediate readers but not in experts or novices. A 3 x 3 ANOVA with Group (Experts, Intermediates, Novices) and Fixation Position (Left, Center, Right) on d’ revealed a significant main effect of Group, $F(2, 34) = 5.41$, $p = .009$, in which the only group difference was that experts performed better than novices in general (LSD tests, $p < .05$). A main effect of Fixation Position was observed, $F(2, 68) = 48.8$, $p \leq .0001$, in which performance was better at the Center than the Left positions and at the Left than the Right positions (LSD tests, $p < .05$). The interaction between Group and Fixation Position was significant, $F(4, 68) = 4.26$, $p = .004$ (Figure 3a).

We subsequently analyzed the effect of Fixation Position for each group separately. The main effect of Fixation Position was significant in each group, all $p$s < .004. For experts and novices, performance was the best at the Center, while performance at the Left and the Right position was similar (LSD tests, $p < .05$), suggesting that the OVP curve was largely symmetrical. However, for intermediate readers, performance at the Center was better than the Left position, which was in turn better than the Right position. In other words, we observed a left OVP with single notes only for the intermediate readers but not for experts or novices.

For RT, the main effect of Fixation Position was significant, $F(4, 68) = 8.14$, $p = .0003$, with faster responses at the Center than the other two positions (LSD tests, $p < .05$; Figure 3b). The main effect of Group and its interaction with Fixation Position was not significant ($F$s < 1).

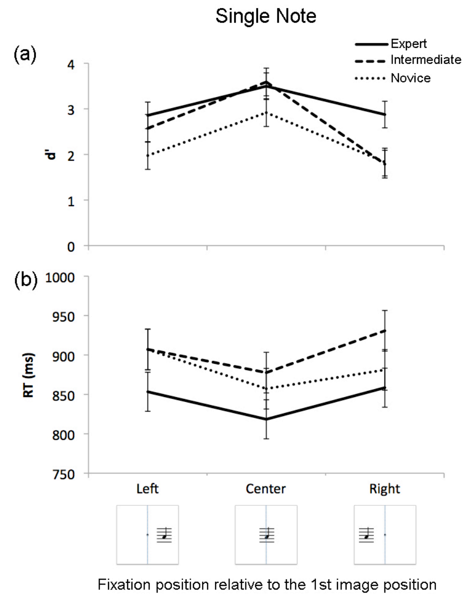


Figure 3. Matching performance for single notes in d’ (a) or RT (b) with different fixation positions relative to the presented images.

## Perceptual fluency

As expected, experts had the highest perceptual fluency for notes, followed by the intermediate group and then by the novices. A one-way ANOVA for Group (Experts, Intermediates, Novices) on duration threshold for notes revealed a significant main effect of Group, $F(1, 34) = 19.8$, $p \leq .0001$, where the performance for each group was significantly different ($M_{Exp}$ = 316.5 ms; $M_{Int}$ = 680.4 ms; $M_{Nov}$ = 930.9 ms; LSD tests, $p < .05$). In contrast, duration threshold for letters was similar for all groups ($M_{Exp}$ = 186.4 ms; $M_{Int}$ = 207.5 ms; $M_{Nov}$ = 233.9 ms; $F < 1$), suggesting that experts have a higher perceptual fluency for notes, which cannot be explained by a general perceptual advantage.

## Predicting the degree of asymmetric OVP with perceptual fluency with notes

Does the degree of asymmetry of the OVP curve increase with one’s reading ability? We addressed this question by computing the degree of asymmetry of the OVP curve for note sequences using the measure $d'_{Left} - d'_{Right}$ in each music reader (novices were excluded in this analysis). A significant correlation was observed between the degree of asymmetry and individual perceptual fluency, $r = -.48$, $p = .015$, $df = 23$ (Figure 4a). A similar trend was observed at far positions ($d'_{FarLeft} - d'_{FarRight}$), though it did not reach significance ($r$ = -.27, $p$ = .19). These suggest that the left viewing position of sequences becomes more optimal during the development of music reading skills.

For single notes, the correlation between the degree of asymmetry of the OVP curve ($d'_{Left} - d'_{Right}$) and individual perceptual fluency approached significance in an opposite direction (r = .37, $p$ = .066, $df$ = 23; Figure 4b). The advantage of left viewing position gradually diminished with better music reading skills.

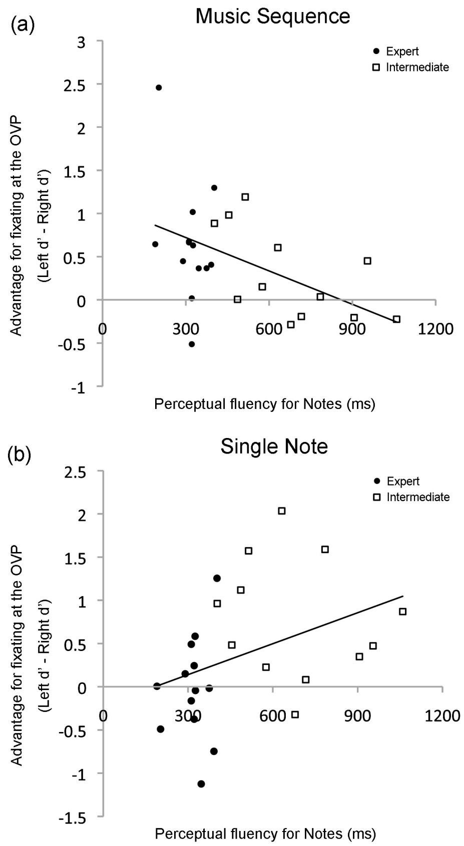


Figure 4. Scatter plots between perceptual fluency for notes and individual degree of asymmetry of the OVP for note sequences (a) and single notes (b).

## Discussion

### For three-note sequences

For three-note sequences, performance was in general the best at the center position, consistent with the highest acuity at fovea. Importantly, we observed an OVP biased to left in music reading experts but not in intermediate or novice readers. Since music reading shares a left-to-right reading direction with word reading but not the hemispheric dominance or asymmetric information distribution, our results suggest that extensive reading experience in the left-to-right reading direction is sufficient to lead to a left-biased OVP in reading.

Our results also suggest that a biased OVP is gradually developed through reading training. For novices, recognition performance is similar across viewing positions and none of the viewing positions is 'optimal'. When music reading skills develop, the OVP is gradually shifted to the left, suggested by the correlation between the degree of asymmetry in the OVP curve and individual music reading ability. Note that our results cannot be explained by the reading habits of other languages (e.g., Chinese and English for our participants), since all of the participants had the same left-to-right reading habit, while only experts produced a left OVP for music sequences.

While our results suggest that reading direction is a major factor leading to a left-biased OVP in reading, the OVP may also be modulated by other factors, such as the left-hemispheric lateralization for language functions (Brysbaert, 1994; Hunter et al., 2007) and an asymmetric information structure of words (Deutsch & Rayner, 1999; Farid & Grainger, 1996). It is worth noting that different types of word information may become important depending on the OVP task, such as word naming, identification, lexical decision, or word matching tasks (e.g., O'Regan, 1984; Deutsch & Rayner, 1999; Nazir et al., 2004; Farid & Grainger, 1996; Stevens & Grainger, 2003). To evaluate the effect of general information structure of words on the OVP, one should consider whether any observed OVP pattern is solely determined by the characteristics of the specific sets of word stimuli, especially for the distribution of information important for the testing task. In any case, even without an asymmetric information distribution or hemispheric dominance, as in the case of isolated music sequences in the current study, a left OVP can still be observed. It suggests that these are not necessary factors leading to a biased OVP.

### For single notes

For single notes, we observed a left-biased OVP among intermediate readers but not in experts or novices, and the left bias of the OVP decreased with enhanced music reading fluency. There are multiple ways to interpret these findings. First, the performance for experts approached ceiling for all viewing positions (the mean d' was larger than 3 and the mean accuracy was larger than 90% for all viewing positions) such that potential differences across viewing positions failed to emerge. Indeed, within the experts whose average accuracy for the Left and Right positions < 90%, a left-viewing advantage emerged numerically (d' = 2.39 for Left; d' = 2.08 for Right; N = 5), supporting the idea that a ceiling effect prevented a left OVP to be observed among experts. According to this explanation, the OVP for both music sequences and single notes are both biased to the left. Another possible explanation is that the asymmetric OVP effect for single notes simply becomes weaker as in the case of word reading that the asymmetric OVP effect was weaker in short words than long words; Hunter et al., 2007; Ellis, Young, & Anderson, 1988). This may be caused by a weakened influence from reading direction on short sequences as experts are able to skip them during reading, and such tendency may become larger with better music reading skills.

It has been proposed that reading direction may partly underlie visuospatial asymmetry effects observed in the processing of some visual stimuli, such as identity or affect judgments for faces (Vaid & Singh, 1989; Brady, 2011), or bisection of straight lines (Chokron & Imbert, 1993; see also Kazandjian & Chokron, 2008). Our current results suggest that the visual field asymmetry caused by habitual word reading direction is not generalizable to all domains of object recognition. Specifically, a left-biased OVP for English words is presumably shared by all of our participants who are either English or Chinese-English bilingual readers (O'Regan et al., 1984), while the visual field asymmetry for musical notation varied across groups. In particular, our novices, who did not have music reading experience and thus were most vulnerable to potential transfer effects from word reading habits, did not show a bias that was consistent with the asymmetry observed in word processing. Further studies should investigate why the visuospatial biases stemmed from reading direction generalize to faces and line bisection but not to musical notes.

## Conclusions

In this study, we demonstrate with the case of music reading that a left-to-right reading direction is sufficient to lead to a left-biased OVP in expert reading. The OVP for music sequences may gradually shift to the left in the course of music reading training as reading skills improve. Our failure of observing a left-biased OVP in music sequence processing in novices suggests that the asymmetry effect created by word reading habits is not generalizable to all domains of object recognition. In contrast, it may be a result of learning changes during the development of reading expertise.

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