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The Effects of Melodic Grouping and Meter on Eye Movements during Simple Sight-Reading Tasks

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ABSTRACT

This study concerns the processes of eye movements during simple sight-reading tasks, concentrating on the processing of melodic groups separated by larger intervals and the effects of metrical placement of such groups. Thirty-two participants with varying musical background sight-read eight short melodies in two separate sessions. Eye movements during playing were recorded using an eye-tracker, and the performances on an electric piano with sequencer software. The melodies in question were of two types: melodic groupings were either aligned with the metrical divisions or made to overlap with them. The results indicate that reinspections to previously fixated notes during sight-reading increased with previous musical experience. During the performance of a single melody, the alignment of melodic groups with metrical units led to a gradual decrease of reinspections. Within the melodic groups themselves, the second notes of the groups received the largest total processing times. In addition, processing differences for notes involved in larger melodic intervals emerged depending on the visual placement of the notes within, or below, the staff system. Possible explanations of these findings as well as implications for future sight-reading studies will be discussed.

I. INTRODUCTION

In previous eye tracking studies on music reading, the tasks have varied from simple pattern-matching (*e.g.*, Burman & Booth 2008; Waters & Underwood 1998), through silent music reading (*e.g.*, Polanka 1995) and tapping notated rhythms (*e.g.*, Kinsler & Carpenter 1994), to sight-reading actual musical works while playing an instrument (*e.g.*, Furneaux & Land 1999; Gilman & Underwood 2003). In most of these studies, the focus has been on the broad differences between more and less experienced sight-readers. Small numbers of participants, often in connection with relatively complex musical situations, have not yet given highly generalizable results. We believe that the time has come to start systematic eye-tracking studies focusing on basic notational and music-theoretical factors, in order to reach a more profound understanding of the complex process of music reading. In this study we examine the processing of large intervals and melodic groups in a simple sight-reading task. The study presented here is a part of a research project in which eye movements and skill development in music reading are studied from multiple perspectives.

Eye movements in music reading

Eye movements consist of short stops, or *fixations*, and rapid shifts from one fixation to the next, called *saccades* (see, *e.g.*, Rayner 1998). The use of *eye-tracking*, the tracking of the fixations and saccades during the inspection of a given stimulus has a long research tradition in, for instance, text reading or picture inspection, but studies on eye movements in music reading are still scarce. Although some general aspects about music reading, such as the average length of fixations being 200-400 ms, and differences between more and less experienced music readers have been established, the few studies done on eye movements in music reading have focused heavily on the eye-hand and perceptual spans of more or less experienced music readers, and the fine-grained structures of music have not yet been addressed. (For a review on eye-tracking research on music reading, see Manell & Hébert 2008).

An exception in the line of research mentioned above is a study by Polanka (1995) that addresses the differences between better and poorer sight readers in simple sight-reading tasks varying in pattern complexity (stepwise vs. triadic patterns) and size (3 or 4 notes). In that study, the melodies were presented without bar lines. The participants processed three-note patterns as larger units, i.e. with longer saccades, than stepwise patterns, showing that participants with musical background were able to use their background knowledge to form melodic groups or "chunks". Nevertheless, although the inspection of saccade lengths does indeed reveal the possibility of a chunking strategy in certain occasions, that measure may not give enough evidence on information processing. This is because, as commonly acknowledged, information appears to be collected only during fixations (Rayner 1998). In order to better understand the connection of eye movements to the cognitive processing of musical notation, we should preferably focus on the points of fixations.

In reading studies of the past few decades, the use of eye-tracking has produced a number of potential measures that we believe can also be applied to the research in music reading. The eye movement measures applied in the present study are the same as used in studies by Hyönä and colleagues (see, *e.g.*, Hyönä, Kaakinen & Lorch 2002; Hyönä & Nurminen 2006). The measures are *total fixation time*, *first pass fixation time* and *look back time*. Total fixation time is defined as the sum of the durations of all fixations landing on a certain area. It can be divided into first pass and second pass fixations. First pass fixation time measures the amount of time spent on a specific area (i.e. a word or a note) when it is encountered for the first time. The term "second pass" fixation, on the other hand, refers to the reinspections of a specific area after fixating on other areas in between (that is, after the area in question has first been left following the first pass fixations). These reinspections are often called "look backs", the term "look back time" thus referring to the total time spent on reinspecting the area in question.

In reading studies, first pass fixation time has been taken to represent the most immediate effects of the cognitive processing of a certain text segment, while look back time, on the other hand, has been understood to represent the delayed effects of a word or a sentence (Hyönä, Lorch & Rinck 2003). Previous findings on music reading indicate that poorer sight-readers make less and longer fixations than more skilled sight-readers (*e.g.*, Gilman & Underwood 2003; Truitt, Clifton, Pollatsek & Rayner 1997). Thus, the effect of first pass fixation time in sight-reading can be assumed to be somewhat similar than in word recognition during text reading; poorer sight-readers make longer first pass fixations since they have more trouble in decoding the symbols, whereas experts can process the symbols and move on more quickly.

In sight-reading situations, the efficient performing of notation requires planning and preparing, which has to be done within the given time frame. For this reason, the eyes move somewhat ahead of the point in music that is being executed by the player's hands. This gap between the point of execution and the point of gaze is called the eye-hand span (*e.g.*, Manell & Hébert 2008). It has been documented that more experienced sight-readers have a longer eye-hand span than novices, and that they thus look farther ahead while playing (*e.g.*, Gilman & Underwood 2003; Truitt et al. 1997). Still, working memory capacity sets limitations to the number of notes kept in memory before execution, and this could mean that even experienced music readers have to stop somewhere looking ahead and return to, if not to the current place of execution, at least nearer to it, since collecting more information might disrupt the performance. This would especially become apparent when skilful sight-readers are asked to play in slow tempo and the mere decoding of information does not take all of the time available. All in all, eye movements from notes to previously inspected ones, i.e. look backs, can be expected to be more frequent for experienced music readers, whereas novices in a corresponding situation and time restrictions would spend more time on first pass fixations.

Research questions

The purpose of this study is to focus on the processing of a basic notational factor, a musical interval. One may hypothesize that when playing the piano, stepwise melodic movement may be executed mostly through motor control, but larger intervals would require identification procedures that are reflected in eye movements as well as in performance. A tentative hypothesis might be that for relatively inexperienced music readers, identificatory problems would cause longer first pass fixation times at the beginnings of melodic groups separated by larger intervals. However, it is also possible that larger melodic intervals are problematic primarily when they result in melodic groupings that are out of phase with the metrical groupings of the music. By studying eye movements, we will examine the processing of these melodic groups and the large intervals surrounding them, in order to find out how fixation time is distributed among certain parts of a score in different tasks.

In order to gain more insight into the way in which the time constraints of music reading are reflected in eye movements, we will address our questions through an experiment designed to bring to the fore the difference between sight-readers with and without difficulties in playing the tasks in the specified tempo. Our main research questions may thus be summarized as pertaining to effects of expertise and skill development, on the one hand, and more general effects of melodic grouping and metrical structure, on the other:

A. Effects of expertise and skill development

- How do the performances of more and less experienced music readers differ in simple sight-reading tasks?
- Is there an effect of skill or skill development in look backs?

B. Effects of melodic grouping and metrical structure

- Does the organization of notes into metrical units affect their processing, as reflected in relative fixation times?
- In a stepwise melodic context, does the metrical location of large intervals affect the global processing of simple sight-reading tasks?
- How is fixation time allocated to the individual notes of melodic groups (separated by larger intervals)?
- Does the metrical location of a large interval affect the processing of notes involved in this intervallic leap?
- Does the registral direction of large intervals affect the processing of notes involved in it?

II. METHOD

Participants

The participants were 49 future elementary school teachers (MA students; 42 females and 7 male). The pool of participants was chosen from the group of second-year students taking part in a two-semester long compulsory music training period, including 20 hours of group piano lessons, the selection criterion being that all of them attended piano lessons by the same music teacher. Participation was voluntary, with a possibility of receiving course credit.

Materials

Eight different 5-bar melodies in C major were composed for this study. Each melody ended on the pitch E4 and had a melodic range from C4 to G4, so that melodies could be executed without moving one's hands. In the notation, the fingering for the first note (C4 or G4) was marked with a number (1 or 5). All of the melodies consisted of quarter notes, apart from a final whole note in the fifth bar. The melodic movement in each melody was primarily stepwise, with the exceptions of two larger intervals – a perfect fourth (P4) and a perfect fifth (P5) – at the temporal distance of one measure from one another. The melodic groupings due to these larger intervals were either aligned with the metrical structure by setting the leaps at bar lines, or made to overlap with metrical divisions.

For the purpose of each session (see below), we used four interconnected melodies, exemplified in Figure 1 by the ones applied in the first session. Melodies (a) and (b) begin from C4, proceeding in stepwise movement to the first intervallic leap, a P4, beginning on the note G4. The difference between these melodies lies in that the intervals larger than a semitone occur at bar lines in melody (a), whereas the corresponding leaps in melody (b) are shifted to occur two beats later, in the middle of measures 3 and 4. Melodies (c) and (d) are simply inversions of the first two melodies, the inverted contour beginning from G4. The four other melodies used in the second session were composed according to the same criteria as the ones seen in Figure 1.

Figure 1. Melodies used in the first session: (a) the original melody, with larger intervals at bar lines; (b) otherwise as the original, but with the larger intervals shifted ahead by two beats; (c) an inversion of a; (d) an inversion of b.

Procedure

Each student took part in two different sessions, the first of which took place at the beginning of their music training period. The participants were tested individually in a laboratory, in the presence of an experimenter (MP). During the session, each participant was instructed to sight-read four short melodies on an electric piano in time with a metronome set at 60 beats per minute. Each notated melody (see Fig. 1) was separately displayed on the computer screen concurrently with the first metronome beat. The participants were told to look at the melody during four initial metronome beats, after which they should start playing. Eye movements during playing were recorded using a Tobii 1750 eye tracker, and the performance with sequencer software. The same procedure with different but corresponding melodies was repeated in another session after three months (16 h) of piano lessons.

III. RESULTS

Data from 14 participants were excluded from the analysis due to unsuccessful eye tracking data in at least one of the eight tasks. In addition, 3 participants were excluded due to missing MIDI recordings, or too poor performances (leading to difficulties in matching the notated melody with the fragmented performance).

The participants' musical background was controlled with free, written reports. Among the remaining 32 participants, 12 had no previous experience in playing music or music reading, 11 of them had 1–6 years of practical experience of these activities, and 9 had a longer experience than 6 years, the latter two groups reporting to understand notation. In the following, these three groups will be called "novices", "amateurs", and "experts".

A. Effects of expertise and skill development

The effects of expertise and skill development will be studied from two perspectives. First, we will focus on the errors in and timing of performances. Second, we will trace the effect of skill development from eye movements, focusing on the reinspections of notes.

The performances of more and less experienced music readers

It was hypothesized that the larger intervals would cause difficulties in performances for novices and amateurs in the first measurement, but that the errors would diminish with practise. The sequencer-recorded performances were thus subjected to an analysis of errors made in the performance of the two intervallic leaps within each melody. For each recorded performance, we controlled the presence of the four notes participating in the two larger intervals (1st and 2nd notes of both intervals). Errors were initially coded according to three categories: (i) wrong, uncorrected notes, (ii) wrong notes followed by correction, and (iii) missing notes. However, the latter two categories collected only a total of 9 errors (this may partly reflect the difficulty of analyzing the player's intention), and thus all of the errors concerning one of the four critical notes were finally treated without distinguishing between error types.

In the following, the statistical analysis was conducted using the Kruskal-Wallis analysis. As expected, skill level had an effect on the accuracy of the performance, considering errors in performing the 4 notes included in large intervals. Novices made significantly more errors in the first and second measurements (M = 2.50, SD = 2.39 and M = 2.42, SD = 2.64, respectively) than amateurs (M =.27, SD = .47 and M = .09, SD = .30, respectively) and experts, who performed completely without errors (M = .00, SD = .00 for both measurements), $\chi^2(2)$ = 12.04; p = .002 for the 1. measurement and $\chi^2(2)$ = 19,96; p = .000 for the 2. measurement. There were no significant effects for skill development between the two measurements for any of the groups.

The timing of performances was analyzed using data which was quantized in the sequencer program (Power Tracks Pro Audio) at the level of sixteenth-notes. As any tempo difficulties in the first and last measures of the melodies would be largely irrelevant for our central questions concerning the larger intervallic leaps, the temporal duration of the performance during measures 2–4 was chosen for measuring the correctness of overall tempo. For each performance we thus coded the duration of the performance, in the corresponding number of sixteenth notes according to the given metronome setting, from the onset of the first note of the second measure to the offset of the last note of the fourth measure. Accordingly, an in-tempo performance would be assigned the value 48 (which is the number of sixteenth-notes in three measures played according to the metronome).

In the first measurement, the tempo analysis (Kruskal-Wallis analysis) revealed a highly significant difference ($\chi^2(2)$ = 10.57; p = .005) between the performances of novices (M = 51.33, SD = 5.83), amateurs (M = 47.86, SD = 0.55) and experts (M = 48.03, SD = 0.20). A significant difference ($\chi^2(2)$ = 6.96; p = .031) between the three groups was found in the second measurement (novices: M = 49.02, SD = 3.31; amateurs: M = 48.48, SD = 1.23; experts: M = 48.00, SD = 0.00). In both measurements, the novices were always the worst in performing in correct tempo, as might have been expected. In addition, only novices appeared to show an improvement in timing between the first and second measurements, but the improvement did not reach significance (Mann-Whitney, Z = -.348; *p* = .728).

Effects of skill and skill development for eye movements

A measure of overall fixation time for the sight-reading task was determined in accordance with the range of the above tempo analysis. Overall fixation time for each performance was thus defined as the total duration of all fixations beginning from the first fixation to measure 2, and ending before the first fixation to measure 5 (it was required, though, that the participant would have progressed linearly through fixations to the previous measures, and had a fixation to the third note of measure 4). In order to eliminate the effect of individual differences in fixation lengths, all of the measures used in the analysis of eye movements were based on percentages of the overall fixation time. Thus, *total fixation time* for a given note, as well as its components, *first pass fixation time* and *look back time*, will be treated here as percentages of the overall fixation time for measures 2–4.

It was hypothesized that skill differences between the participant groups and skill development between the two measurements would be reflected in changes in how the overall fixation time would be allocated to different types of fixations. More specifically, based on previous research on the behaviour of experienced sight-readers and knowing that experienced music readers look further ahead while playing, it was hypothesized that in this study experts would make more look backs than novices. On the other hand, it was expected that novices would show an increasing amount of look back time with skill development.

The overall time spent looking back to already read notes was calculated simply as a sum of the look back times for individual notes. Thus, for the novices the average percentage of overall fixation time spent for look backs (reinspections of notes) was 11.60 (*SD* = 5.25) in the first measurement, and 14.26 (*SD* = 8.89) for the second measurement. In comparison, it was found that experts did, indeed, spend more time on looking back to previous notes than novices (*M* = 18.99, *SD* = 9.95 for the first and *M* = 24.07, *SD* = 8.95 for the second measurement). For both of the measurements, the Kruskal-Wallis analysis revealed significant differences ($\chi^2(1) = 3.96$; *p* = .047 and $\chi^2(1) = 4.54$; *p* = .033, respectively). However, no significant effect in look back times was found between the measurements. This suggests that the skill development in this respect between the measurements may have been marginal.

B. Effects of melodic grouping and metrical structure

In order to concentrate on eye movements within the time restrictions of playing in tempo, only those recordings that were played in time with the metronome were chosen for a more detailed analysis. In compliance with the temporal analysis presented above, all and only those performances were accepted in which the total time consumed for executing measures 2–4 corresponded to 48 sixteenth-notes (12 quarter-notes, quantized on the sixteenth-note level). Given the lack of significant effects for skill development in both performance and eye movements (see above), it furthermore seemed warranted to combine the recordings from both laboratory sessions in the same analysis. The following results thus pertain to performances played in the correct tempo, regardless of the general skill level of the participant or the time of execution. All in all, 189 recordings by 32 participants were included in the following analysis. Of these, 90 included intervallic leaps at bar lines and 99 between the 2nd and 3rd beat (see Table 1).

Table 1. The number of recordings played in accordance with a metronome in relation to task types and participants' musical background.

Group	Task: Large interval at bar line	Task: Large interval between 2nd and 3rd beat	Total
Novices	21	26	47
Amateurs	34	38	72
Experts	35	35	70
Total	90	99	189

Effects of metrical structure

Before examining the specific effects of large intervals on eye movements, it is pertinent to pay attention to some more general findings due to the metrical division of the music. The 4/4-meter implicit in the melodies should be seen both as a cognitive factor, imposing a series of metrical accents on the melodic line, and as a visual factor, facilitating the grouping of the visual note symbols in groups of four. It might therefore be expected that either the cognitive organization arising from metrical accents or the visual outlook of the note text, or both, would have some effects on the eye movements. For instance, one might tentatively hypothesize that the first notes in each measure would receive the longest fixation times, functioning as visual reference points for the rest of the measure. Some effect of meter is, indeed, already seen in Figure 2 which shows the average fixation times for the individual notes in measures 2, 3 and 4 for the whole set of recordings played according to the metronome (*n* = 189). The lines represent total fixation time and its two components – first pass fixation time and look back time. Disregarding the placement of the larger intervals for now, the four notes in each measure show a largely rising trend in the average total fixation times. In other words, the above tentative hypothesis is disproved: it is exactly the metrically accented notes that receive the *shortest* total fixation times. As the figure reveals, the first notes in each measure also receive the shortest first pass fixation times.

Such effects of meter – whether they reflect a cognitive organization by metrical accents or simply a visual grouping tendency due to the bar lines – may be verified by taking the means and standard deviations for the values of the first, second, third and fourth notes across measures 2, 3 and 4 (see Table 2). The differences in values received by the four notes are highly significant according to the Friedman test for both total fixation time ($\chi^2(3) = 20.86$; *p* = .000) and first pass fixation time ($\chi^2(3) = 16.90$; *p* = .001). Thus we may conclude that the total fixation time spent on notes in each 4/4 measure increases from the first note onwards, and that the first note of the measure tends to get a shorter fixation time in comparison to the notes following it. On the other hand, the differences in values observed for look back time are not significant ($\chi^2(3)$ = 5.02; *p* = .171).

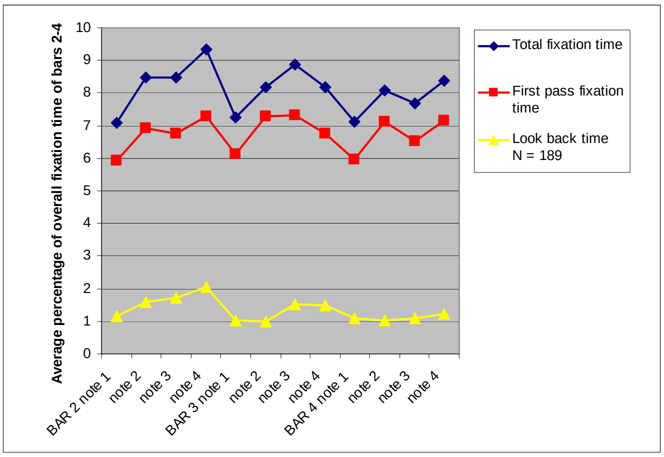

Figure 2. Average fixation times for individual notes in measures 2, 3 and 4; total fixation time, first pass fixation time and look back time (*n* = 189).

Table 2. Average fixation times for the four notes in measures 2, 3 and 4, presented as percentages of the overall fixation time (*n* = 189).

Note nr.	Total fixation time	First pass fixation time	Look back time
	M / SD	***M / SD***	***M / SD***
1.	7.15 / 2.64	6.01 / 2.75	1.09 / 1.40
2.	8.25 / 2.62	7.11 / 2.83	1.21 / 1.49
3.	8.34 / 2.80	6.87 / 2.74	1.44 / 1.76
4.	8.63 / 2.49	7.06 / 2.70	1.59 / 2.11

The alignment of melodic groups with metrical structure

The principal question in terms of our experimental design was the effect of large intervals and their placement within the metrical framework to the eye movements in sight reading. A basic hypothesis concerning melodic cognition would be that processing is facilitated in melodies in which the groups of notes separated by large intervals would be aligned with the metrical divisions, group boundaries thus occurring at bar lines. However, it is unclear what this would mean in terms of eye movements. In the following analysis, we will first focus on the way in which the presumed differences in cognitive processing for the two types of tasks are reflected on the temporal development of fixation times during the task. The reader is warned that we will use the term “melodic group” here to refer to the visual and/or musical groups of four notes separated by large intervals in our experimental tasks. It is, of course, a separate empirical question how the listener in fact cognitively groups the pitches. For our present purposes, it will be convenient to refer to the widely accepted hypothesis that, all else being equal, large registral differences between successive melodic pitches are potentially heard as group boundaries (see, *e.g*., Lerdahl & Jackendoff 1983, 46).

The differences in processing between the two types of tasks were approached by counting the first pass fixation and look back times for each note in measures 2–4 of the melodies. In tasks where large intervals – and thus potential group boundaries – were set at bar lines, Friedman test revealed significant differences between the first pass fixation times received by the different notes in bars 2–4 ($\chi^2(11)$ = 27.97; *p* = .003). The same was true for look back times ($\chi^2(11)$ = 37.80; *p* = .000). On the other hand, such significant differences were absent for those tasks in which large intervals were between the 2nd and 3rd beat (first pass fixation: $\chi^2(11)$ = 17.17; *p* = .103; look back: $\chi^2(11)$ = 17.38; *p* = .097). Figures 3 and 4 show the average first pass fixation and look back times for the twelve notes in the two tasks with a trend line representing the direction of the possible changes.

The trends evident in Figures 3 and 4 may be summarized as follows. When large intervals were set at bar lines, first pass fixations per note tended to increase during the execution of the three-measure long musical passage, whereas look back time per note, in contrast, tended to diminish during the task, in both cases the differences between values received by notes were significant. No corresponding effect was visible for tasks in which the large intervals were between the 2nd and 3rd beat; in this case, the processing notes stayed constant.

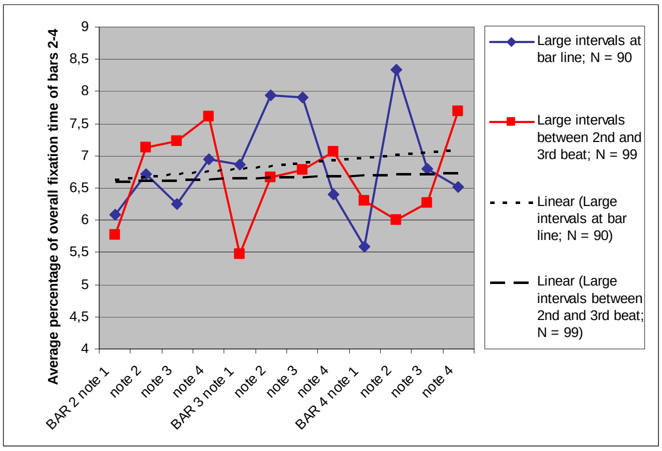

Figure 3. First pass fixation times for notes in bars 2, 3 and 4 in tasks with large intervals at bar lines or between 2nd and 3rd beat.

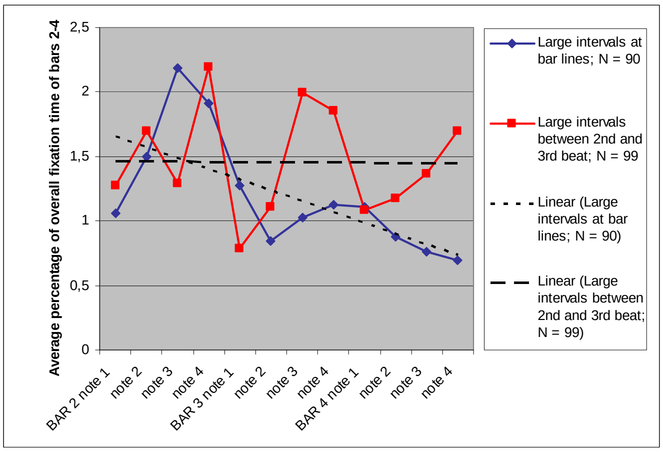

Figure 4. Look back times for notes in bars 2, 3 and 4 in tasks with large intervals at bar lines or between 2nd and 3rd beat.

The processing of melodic groups

Because the melodies used in the sight-reading tasks contained the four-note melodic groups always in one of two locations, it was feasible to approach the processing of such groups by inspecting the values received by notes in measures 3 and 4, which contained the melodic groups in question. When large intervals were set at bar lines, the first separate group of four notes started at the first note in measure 3. In the other case, the melodic group started at the third note in measure 3 (see Figure 1).

Now, as far as eye movements are concerned, it was again unclear how such groupings would be reflected in the fixation times, and whether the placement of the groupings in relation to meter would have to be considered as well in order to account for possible effects of grouping. One possible hypothesis would be that the first notes of melodic groups would receive longer fixation times due to the relative difficulty of identifying a pitch that are arrived at by a leap. Whereas the stepwise melodic movement within the groups might be processed through simple motor control (pressing the consecutive keys with adjacent fingers "one up", "one down" etc.), jumping to a new group by a larger interval would require identifying the new note symbol, perhaps by involving access to long-term memory.

Table 3 shows the means and standard deviations for the values for notes 1–4, averaged over measures 3 and 4. The Kruskal-Wallis analysis for corresponding values for the two types of group placement revealed significant differences in the total fixation time of note 2 ($\chi^2(1) = 7.82$; $p = .005$), and note 4 ($\chi^2(1) = 12.90$; $p = .000$). In first pass fixation times, significant differences emerged for note 2 ($\chi^2(1) = 12.09$; $p = .001$) as well as note 3 ($\chi^2(1) = 6.33$; $p = .012$). For look back time, significant differences as a function of group placement emerged for note 2 ($\chi^2(1) = 4.00$; $p = .046$), note 3 ($\chi^2(1) = 7.41$; $p = .006$), and note 3 ($\chi^2(1) = 5.01$; $p = .025$).

Table 3. The processing of the four notes in bars 3 and 4. Means and standard deviations. Percentage of overall fixation time.

Measure	Note	Task: Large interval at bar line; *n* = 90	Task: Large interval between 2nd and 3rd beat; *n* = 99
		M / SD	***M / SD***
Total fixation time	1.	7.50 / 3.20	6.88 / 3.23
	2.	8.90** / 3.54	7.43** / 3.29
	3.	8.24 / 2.91	8.31 / 3.35
	4.	7.42** / 3.16	9.06** / 3.30
First pass fixation time	1.	6.23 / 3.30	5.89 / 3.28
	2.	8.14** / 3.57	6.34** / 3.21
	3.	7.35* / 2.90	6.53* / 3.46
	4.	6.46 / 3.27	7.38 / 3.67
Look back time	1.	1.19 / 1.86	0.93 / 1.44
	2.	0.86* / 1.68	1.14* / 1.81
	3.	0.89** / 1.53	1.68** / 2.21
	4.	0.91* / 1.66	1.78* / 2.70

Note. Significance in differences between corresponding means.
* $p < 0.05$. ** $p < 0.01$.

In tasks with large interval at bar lines, the second notes in measures 3 and 4 collected longer total fixation times than the corresponding notes in tasks with large intervals between 2nd and 3rd beats. On the contrary, large interval inside a metrical unit induced a longer total fixation times for the final notes in measures 3 and 4 than when large intervals were set at bar lines. It is noteworthy that in both cases the significant difference concerns the *second* note in the melodic group, thus disproving the preliminary hypothesis in terms of longer processing time being allocated for the initial notes of melodic groups. The differences in first pass fixation and look back time reflect the changes in overall processing of the two tasks; the first pass fixation times of notes 2 and 3 were longer for tasks with large intervals at bar lines, and the look back times of notes 2, 3 and 4 for the other task.

As far as the first of these results is concerned, it is interesting that the longer first-pass fixation times observed are here attached to notes that are not only lacking in metrical accentuation but also in melodic accents. That is, the longest first pass fixation times do not accrue to the notes that would be deemed most salient according to various types of melodic accent (such as "interval size accent" or "contour pivot accent"; see Huron & Royal 1996). Rather, it seems that it is conversely the metrically and melodically unaccented notes that get the longest first pass fixations.

The processing of notes included in a large interval

Next, the processing of notes included in large intervals was examined in relation to the task type. The first interval in each task was a fourth and the second a fifth. Here, we compared the values for the three measures received by corresponding notes in the two tasks, the first notes in the first large interval (a 4th), the second notes in the first large interval, the first notes in the second large interval (a 5th) and the second notes in the second large interval.

A Kruskal-Wallis analysis revealed only one, mildly significant difference between the two task types; the first note in the first interval (a 4th) received a longer look back time in the task where the interval was set at bar line (M = 1.91, SD = 3.41) than in tasks where in was within the measure (M = 1.11, SD = 2.75), $\chi^2(1) = 3.92$; $p = .048$. No significant differences were found for the other three notes included in the large intervals.

The registral direction of larger intervals

To answer the last research question on the processing of intervals in different tasks, the effect of registral direction (ascending or descending) of an interval was examined. The rationale for such an analysis is related to the fact that the larger intervals always occurred between the notes C4 or D4, on the one hand, and F4 or G4, on the other. Namely, it might be suggested that relatively inexperienced sight-readers would demonstrate processing differences between the two lower notes and the two higher ones. For instance, if the higher notes would collect longer fixation times, this might be explained in terms of the less characteristic visual outlook of these note symbols (at least compared to the symbol of C4 with its characteristic ledger line), or their less paradigmatic status in music learning (for beginners, the identity of, say, F4 might need to be “counted” from C4). In order to address such questions, the two different large intervals in each task were analyzed separately, as were the types of melodic group placement. Thus, comparisons were done between notes that were, for example, the first note of the first large interval (P4) in tasks where large intervals were located at bar lines, the direction of the interval being the group variable. Table 4 shows the number of eye movement recordings used in the analysis from each kind of task.

Table 4. The number of eye movement recordings with respect to the direction and location of the intervals.

Direction / task type	Interval	
	P4	**P5**
up / bar line	47	47
down / bar line	43	43
up / between 2nd and 3rd beat	51	46
down / between 2nd and 3rd beat	48	53
Total	189	189

There were a number of significant differences due to the registral direction of the larger intervals, revealed by Kruskal-Wallis analyses. In considering these results, the reader may refer to the example melodies in Fig. 1, keeping in mind that the first large interval was always a P4 and the latter a P5.

Total fixation time. For this measure, two significant differences emerged, concerning the second of the two larger intervals. When located at bar line, the first note of a descending P5 collected a significantly longer total fixation time (M = 8.90, SD = 5.08) than the first note of an ascending P5 (M = 5.94, SD = 4.40), $\chi^2(1) = 8.20$; $p = .004$. The similar pattern was visible also in tasks with intervals between the 2nd and 3rd beat, the total fixation time of the first note of a P5 down being longer than the first note of a P5 up (M = 7.96, SD = 3.60 and M = 6.21, SD = 4.13, respectively), $\chi^2(1) = 4.64$; $p = .031$. Thus, in both task types, a descending P5 induced a longer total fixation time for the first note of the interval than the same interval in the ascending direction.

First pass fixation time. Three significant differences emerged concerning the first pass fixations between notes included in ascending or descending intervals. First, the first note of a descending P4 between a 2nd and a 3rd beat collected a significantly longer first pass fixation time (M = 7.48, SD = 4.54) than the first note of an ascending P4 (M = 5.90, SD = 5.12), $\chi^2(1) = 3.96$; $p = .047$. Secondly, for the same task type, the large intervals being between a 2nd and a 3rd beat, the first note of an descending P5 collected a longer first pass fixation time (M = 6.89, SD = 3.75) than the first note of an ascending P5 (M = 5.00, SD = 3.77), $\chi^2(1) = 6.52$; $p = .011$. Thirdly, for the tasks with large intervals at bar lines, the first note of a descending P5 down collected a longer first pass fixation time (M = 7.56, SD = 4.92) than the first note of an ascending P5 (M = 5.34, SD = 4.18), $\chi^2(1) = 5.17$; $p = .023$. Thus, in each case the significant differences in first pass fixation times appeared for the first notes of the large intervals, these notes collecting longer first pass fixations when the interval was a descending one.

Look back time. For this measure, one comparison reached significance. The first note of a P5 down in tasks with large intervals at bar lines collected a longer look back time (M = 1.69, SD = 3.23) than the first note of the P5 up (M = .60, SD = 1.98), $\chi^2(1) = 5.16$; $p = .023$. In other words, when the interval was located at bar line, a descending P5 induced more reinspections of the first note of the interval than an ascending P5. All in all, it seems that when a large interval is descending, its first note induces more processing than the first note of an ascending interval. This pattern was visible in both types of tasks and especially in total fixation times and first pass fixations

IV. DISCUSSION

In their study of errors in piano performance, Drake and Palmer (2000, 25) reported that less skilled pianists’ performances exhibited higher proportions of timing errors, whereas more skilled pianists played better in time, and thus exhibited mainly pitch errors. This was partly confirmed in our results: the proportion of “stammering”, out-of-tempo performances was greater for novices than amateurs and experts, and the experts did not, in fact, make any errors in their performance. This was expected, since the melodies used were created simply keeping in mind the starting point of the novices. We also found no effect for skill development in this respect after a three-month instruction period. This might be due to the use of metronome in laboratory sessions; novice participants still struggling with motor coordination probably found it too difficult to play in time with a metronome. As Susan Hallam (2001, 21) reports in the case of beginning violinists, the novices tended to focus on one facet of decoding notation at the expense of others. In this study, the metronome offered a temporal framework, but the novices were still unable to concentrate on temporally accurate performance while still having problems in pitch recognition and motor execution.

As expected, the experts did turn out to have more reinspections than novices. The reason for this lies probably in the slow tempo and the simplicity of the melodies; experts decoded the symbols quickly, moved their gaze forward and, due to restrictions in time and working memory capacity, returned to already fixated notes to spend the extra time they had. For novices, the processing of notation happened more by relying on first pass fixations.

The most interesting findings reported here relate to those performances played in accordance with the metronome. First of all, it was found that increasing total fixation time from the first note onwards within the notated 4/4 measures suggests that metrical structure does indeed affect the time consumption during sight-reading. For one, this might represent the effect of anticipatory planning of the next measure: as suggested by Drake and Palmer (2000), the planning for the execution of the next notated segment would thus happen at the end of the current one. For another, the increasing fixation time within measures might simply represent the effect of waiting, or spending excess time while waiting for the metrical cycle to be fulfilled. In other words, within the metrical units, the sight-readers would tend to more freely "look ahead" in relation to the tempo, whereas bar lines would signal temporal check points at which the reader would have to wait for the right time to proceed. For our relatively inexperienced sight-readers, single measures would thus not be exceeded in eye movements before the elapsing of the temporal cycle. However, if this explanation is correct, it may be hypothesized that increasing proficiency in sight-reading would allow longer metrical units to be processed in like manner, in which case any possible extra time would be consumed at the ends of larger metrical units (within the limits allowed by working memory capacity).

Secondly, the metrical location of the large intervals and, thus, melodic groups had an effect on reinspection behaviour during performance. Bar lines and large intervals coinciding, the participants reduced their reinspections during the performance of the melody, whereas large intervals inside a bar caused the participants to continue their reinspections during the performance. This might suggest that when melodic group and metrical division coincided, there was an anticipatory effect already during the three bars in question. After the first larger interval, the task would thus be recognized as a relatively simple one – consisting of stepwise melodic groups in each bar – which would lead to a less amount of looking ahead and returning to the point of execution, since nothing too unfamiliar was expected. On the other hand, when large intervals were placed between the 2nd and 3rd beats in the measure, the reinspection behaviour may have remained constant because of the lack of comparable predictability in the melodic structure. This finding is relevant when planning melodies for future eye-tracking studies on sight-reading, and also demonstrates the importance of examining eye movements in music reading as a process, even in the case of a short melody.

Third, the processing of melodic groups revealed one interesting pattern. Contrary to our preliminary hypothesis, it was the second, and not first, notes in the four-note melodic groups that collected the longest total fixation times. This might have two possible explanations, considering the nature of the tasks. The first alternative is that the processing of a large interval causes a delayed effect on the note *following* the note approached by a leap. In reading studies, the processing of a certain problematic sentence might cause some delayed effect, i.e. a long fixation, in the beginning of a next sentence (see, Hyönä et al. 2003). On the other hand, the relatively long total fixation times for the second notes in melodic groups might indicate an anticipatory and/or identificatory process of the stepwise pattern following a large interval; after a, say, a descending interval of a P4, the music reader stops to "check" that the following notes indeed continue in a stepwise fashion. In this case, the stepwise pattern might be perceived within the perceptual span associated with the fixation; a simple pattern ahead does not tempt or force the reader to quickly move her gaze forward. To be sure, both of these explanations are rather speculative: to settle the matter, one would need to conduct a study comparing the eye movements in melodies consisting or several consecutive large intervals versus merely stepwise patterns.

Fourth, the processing of notes involved in large intervals (P4 or P5) as a function of their metrical placement showed a mildly significant difference only for the processing of the first notes of the first large intervals. When the first of the two larger intervals was set at the bar line, its first note collected a longer look back time than when the interval was between the 2nd and 3rd beat. At present, we do not have a convincing explanation for this finding, but it would need further examination.

Fifth, considering the metrical position and registral direction of the larger intervals, it is noteworthy that, the first note of a descending interval seemed to require more processing than the first note of an ascending interval. This pattern was seen in both total fixation times and first pass fixations, and it occurred irrespective of the metrical placement of the interval. Taking into account that the lower notes included in the large intervals in the tasks presented in this study were either C4 or D4, it might be suggested that these symbols are visually relatively simple or salient ones and thus easier to perceive than the other notes included in these intervals, F4 or G4, located towards the centre of the staff system. The suggested "simplicity" of these symbols would obviously have to be understood in relation their more paradigmatic status (at least in the case of C4) as reference points in musical instruction. Such factors might explain why the first notes in descending intervals, F4 or G4, were fixated more than the first notes, C4 or D4, of ascending intervals. Be that as it may, this finding demonstrates the multidimensional nature of a sight-reading task: in addition to meter, melodic grouping, and differences in melodic intervals, also the varying complexity of and familiarity with individual note symbols may present an additional factor that would have to be taken into account in studying the complex process of music reading.

One purpose of this study was to bring into focus some of the minute but yet significant details affecting the process of sight-reading. The topics addressed in previous eye movement studies on music reading, such as the eye-hand span, have been highly complex cognitive processes involving a multitude of musical and cognitive factors. Without an attempt to separate the effects of these factors, the ultimate reasons for, say, the differences in behaviour between skill levels would be left unanswered. The present study has been an attempt to begin a systematic research in this direction.

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