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Unexpected Melodic Events during Music Reading: Exploring the Eye-Movement Approach

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ABSTRACT

Two studies examined the eye-movement effects of unexpected melodic events during music reading. Simple melodic variants of a familiar tune were performed in a temporally controlled setting. In a pilot study with five university students, unexpected alterations of the familiar melody were found to increase the number of incoming saccades to the altered bar and the bar immediately before the alteration. The main experiment with 34 music students, incorporating several improvements to the experimental design, again showed an increase in the number of incoming saccades to the bar before the alteration, but no effects in the altered bar itself. In addition, the bar following the alteration showed decrease in relative fixation time and incoming saccades. These results are discussed with a view to future studies in eye-movements in music reading, emphasizing the need for more systematic research on truly *prima vista* performance and, in general, temporally controlled music reading.

I. INTRODUCTION

Over the past few decades, the use of eye-tracking methodology has greatly advanced the understanding on the cognitive processes related to text reading and the inspection of various types of images (see Rayner, 1998, 2009). In contrast, research on eye movements in music reading has remained underdeveloped (Madell & Hébert, 2008, p.157). The use of eye-tracking methodology could well add to the knowledge on the underlying cognitive mechanisms related to reading and performing music, but many unique features of the visual processing of this special domain are still either left completely unexplored, or are covered by a few independent studies with divergent musical stimuli and research designs (for a similar argument, see Lehmann & Kopiez, 2009). Apart from the complexities of the Western notation system itself, music reading involves an intricate interplay between such human factors as visual attention, musical grouping, expectation and expression, and motor execution; in the present state of the research, there is a need for systematic studies isolating selected aspects of this complex process for careful scrutiny. In this paper we address the problem of investigating the eye-movement effects of unexpected musical events, and demonstrate the first results of such an approach in the context of reading and performing a simple, familiar tune.

Contrary to what many may assume, eyes do not move linearly across a musical score. Instead, eye movements consist of *fixations*, short moments when the gaze is relatively still, and *saccades*, swift shifts between consecutive fixations. In music reading, the average fixation duration has been found to lie between 200 and 400 ms (Madell & Hébert, 2008; Rayner, 1998), though this is subject to great variance between individuals and the music being read, with fixation durations up to 1500 ms and beyond (e.g. Goolsby, 1994b). During a single fixation, readers process information available within their *perceptual span* – that is, the area of accurate vision, which in music reading typically extends 3–5 beats or 4–5 notes to the right from the point of fixation (Burman & Booth, 2009; Gilman & Underwood, 2003; Truitt, Clifton, Pollatsek, & Rayner, 1997). Similarly to text reading, music reading in principle consists of a series of fixations and progressive saccades, each saccade moving the spectrum of accurate vision to a new target location. Occasionally, though, this chain of progressive saccades is disrupted, as the inspections towards upcoming musical material are followed by regressive saccades targeting nearer to the actual point of performance (see Gooslby, 1994a; 1994b).

Fixation durations are considered to reflect the time and effort needed to process the fixated information (see studies on text reading: e.g., Just & Carpenter, 1980). In line with this, musicians with higher skill levels in sight-reading, and thus presumably more efficient mechanisms for transforming the visual stimulus into motoric actions, have been found to operate with shorter fixations than less-skilled sight-readers do (Goolsby, 1994a; Truitt et al., 1997; Waters & Underwood, 1998). In addition, increasing sight-reading skill apparently facilitates processing visually distinct and/or simple groups of notes by single fixations (Gooslby, 1994b; Kinsler & Carpenter, 1995; Polanka, 1995; Wurtz, Mueri, & Wiesendanger, 2009) and, for instance, decreases the fixation time allocated to notes after melodic group boundaries that are due to larger melodic intervals (Penttinen & Huovinen, 2011).

When performing notated music, the gaze moves along the musical score slightly ahead of the current point of execution (see, e.g., Kinsler & Carpenter, 1995). The concept of *eye-hand span* is used to describe this difference between the executed note and the currently fixated one (see, e.g., Madell & Hébert, 2008). More proficient sight-readers appear to operate with larger eye-hand spans than less proficient ones do, given that the span is measured in the number of notes (Furneaux & Land, 1999; Gilman & Underwood, 2003; Truitt et al., 1997). However, when calculating the *time* lag between the gaze and the performance, the average length of the span has been suggested to be consistently around one second (Furneaux & Land, 1999; Wurtz et al., 2009). In addition, the structure of the score appears to have an impact on the eye-hand span, as increasing musical complexity decreases its size (Gilman & Underwood, 2003; Truitt et al., 1997; Wurtz et al., 2009).

Although revealing the above-mentioned general features of eye movements in music reading, prior studies have tended to overlook two major methodological issues. The first issue concerns the type of music reading tasks given to study participants. Music reading is usefully divided into three different categories: silent reading without a simultaneous performance, i.e. scanning or reading through sheets of music; rehearsed reading while performing a piece; and sight-reading *per se*, i.e. performing a piece truly *prima vista* whereby a performer must quickly identify the specific musical patterns and act accordingly within the given time frame (see Lehmann & Ericsson, 1996). One of the potential strengths of the eye-tracking methodology is that it could help us understand the differences in the cognitive requirements of such different music-reading contexts. Unfortunately, however, many studies have used the term "sight-reading" quite vaguely, allowing participants to examine the score for a more or less defined time period before the actual performance task. While this admittedly corresponds to how every-day music reading often involves some form of preparation, it also renders the interpretation of the eye-movement indicators more difficult. In recording eye movements with the accuracy of milliseconds, we need to be aware that familiarity with the notated music tends to affect the reading (see, e.g., Goolsby, 1994a; Kinsler & Carpenter, 1995).

Second, prior studies have not directly addressed one of the key features of music reading, namely temporal control. In the majority of published studies on eye-movements in music reading, the performance tempi have not even been totally controlled for (with few exceptions: Kinsler & Carpenter, 1995; Penttinen and Huovinen, 2011), leaving the possibility open that some of the findings could have been influenced by the participants' own, mutually different, choices of tempo. Nevertheless, temporal control – in the simple sense of adhering to a given performance tempo – could well be a key aspect through which research of music reading might potentially contribute to the larger research on the eye-movement indicators of cognitive processes.

The present studies examine the eye-movement effects of unexpected musical events during a temporally constrained, simple music reading task. The notated stimuli contained variations of a familiar melody, each containing a deviant bar with respect to the original. No additional time was given for preparation of the performances: therefore, the altered bars had to be read and performed truly *prima vista*. We assume that confronting unexpected notational information within a familiar melody likely increases the cognitive strain for the performer, requiring her/him to adjust the reading of the musical score in such a way that a continuous (and preferably correct) performance at the chosen tempo is possible to obtain. Our working hypothesis is that unexpected events should thus affect the allocation of fixation time and/or saccadic movements during sight-reading. Given that the issue of unexpected musical events has not – to our knowledge – been addressed prior to this study in the relevant eye-movement literature, our interest in the topic is also methodological. By suggesting some ideas for how such phenomena might be addressed through eye-tracking methodology, we hope to indicate possibilities for future research in this area.

II. STUDY 1

The main purpose of the pilot study was to test a research design suitable for examining the eye-movement indicators of unexpected melodic events. We also expected to receive preliminary findings supporting the hypothesis that in a temporally controlled performance, encountering unexpected melodic events causes deviations from the average course of reading. In particular, it was hypothesized that such events would result either in (i) increased allocation of fixation time for the problematic bars, or (ii) greater amount of incoming saccades for the bars in question, due to reinspections.

A. Method

1) Participants. A pool of 49 Finnish university students (future elementary school teachers) participating in a larger study on eye movements in music reading (see Penttinen & Huovinen, 2009; 2011) formed the original data set, from which five female participants (age 22-41) were chosen for the present pilot study based on their (i) extensive musical training and music reading ability, (ii) successful eye-movement and performance recordings in all three measurements for the three melodies in question and (iii) temporal and melodic accuracy of the performances. All of the five participants had received formal instruction in a musical instrument for a minimum of ten years, all of them had taken piano lessons, and three of them had conservatory degrees in music performance. Like all of the participants in the original data set, they took part in a compulsory music course at their university, during which the measurements took place.

2) Stimulus Materials. Variations of a notated melody of the well-known children's song "Mary Had a Little Lamb", in the key of C major, were used as stimulus materials (see Figures 1 and 2). Motoric complications in executing the melodies on a piano keyboard were avoided by requiring the use of white keys only in a stationary hand position in which each of the five notes of the piece (C4–G4) matched one of the player's right hand digits. Three variations were written using Finale music notation software. To create a variation, we selected one bar from the original melody in which the first note of the bar proceeded stepwise up from the previous note. Subsequently, all of the notes in this target bar were moved one step down so that *the first note of the target bar repeated the last note of the previous bar*. Hence, the target bar did not present salient visual complexities in relation to its immediate context, nor did it alter the original melody's rhythmic features.

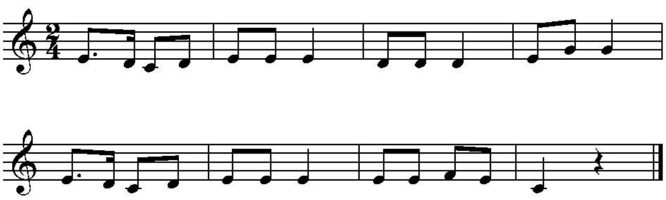

Figure 1. Variation 1 as applied in the pilot study. Notes in bar 7 have been moved one step to create a melodic deviation. For Variations 2 and 3, see Variations C and B in Figure 2.

3) Apparatus. Eye movements during playing were recorded using a Tobii 1750 Eye Tracker manufactured by Tobii Technology AB (Stockholm, Sweden). The infra-red cameras tracing the position of the participants' pupils were integrated into the body of the same computer monitor from which the stimuli were presented; thus, the participant examined the notated melody as it would have appeared on an ordinary computer screen. No chin or head supports were used. Both eyes were tracked with a frame rate of 50 Hz and the accuracy of the recording system was 0.5 degrees. The screen resolution was 1024 x 768 pixels. On the screen, the width of one staff was 30.8 cm (12.1 in) and the height 1.8 cm (0.7 in). A Yamaha electric piano was used for the performances, which were recorded using sequencer software (Power Tracks Pro Audio).

4) Procedure. Each participant took part in three different measurement sessions in the course of their nine-month long music course. In this study, we will not consider the longitudinal aspect of the data set, as the participants' extensive musical training made their performances equally accurate in all three measurements and the purpose here is to develop a research setting for the upcoming Study 2.

The participants were tested individually in a laboratory, in the presence of an experimenter (author MP). At the start of the session, they were first introduced to the equipment and asked to adjust the piano seat to a comfortable height. The computer screen was located behind the electric piano, distance from the participant being ca. 60 cm (ca. 24 in), corresponding to how sheet music would be placed in normal playing situations. After calibrating the eye-tracker, the participants were accustomed to the setting by letting them play short diatonic melodies in C major composed for another experiment (see Penttinen & Huovinen, 2009; 2011). The melodies consisted of quarter notes ranging from C1 to G1, and were performed in time with a metronome set at 60 M.M. Next, the experimenter performed to the participant the original version of "Mary Had a Little Lamb" in time with a metronome set again at 60 M.M., and asked whether the participant recognized the melody (all of the five participants considered did). The purpose here was to ensure that all participants were familiar with the melody. The participant was then instructed to play according to the music that would appear on the computer screen and wait for four metronome beats – after the appearance of the melody – before starting the performance. In the first measurement each participant performed Variation 1, in the second Variation 2, and in the third Variation 3.

5) Data analysis. The data analysis applied the ClearView 2.7.1 analysis software. A fixation was defined as an event during which the gaze dwelled within a 40 pixel radius for 60 ms or more. So-called Areas of Interests (AOIs) were drawn around each bar to assign each fixation into its target bar. The 543 fixations in the data set contained only 3 outliers, i.e., fixations landing outside the AOIs.

During the four-second temporal interval between the appearance of the visual stimulus and the initiation of the performance, the participants were mostly found to inspect bar 1: consequently, we limited our analysis to bars 2–7. Note that also the last bar was omitted both due to its exceptional role in marking the ending of the melody and because of its visual difference from the previous bars.

B. Results

For each of the three melodic variations, Table 1 presents the average fixation times for bars 2–7 as percentages of total fixation time for the bars in question. The altered bars are marked in boldface. It appears that for the five participants considered, there is no evidence of more time being spent on the altered bars across all of the variations. Bar 7 in Variation 1 might seem to be an exception, but it should be noted that bar 7 has acquired relatively long fixation times in all three melodies.

The percentages of incoming saccades, i.e. saccades targeting a given bar after a fixation in another bar, are given in Table 2. Supposing the score would be read in a linear fashion, all of the bars receiving only one incoming saccade (that from the previous bar), each bar would receive a value of ca. 14%. In fact, however, the altered bar and the preceding bar in each variation together collected nearly 50% of all incoming saccades. The pattern is similar in all three variations, though in Variation 1 the standard deviations appear greater than in the other two variations.

Table 1. Relative fixation time for bars 2-7 (in %) across the three variations: means and standard deviations (in parenthesis) for the five participants. Note: The values for altered bars are bolded.

	Variation 1	Variation 2	Variation 3
Bar 2	13.9 (3.6)	15.9 (1.6)	13.2 (1.8)
Bar 3	14.2 (3.1)	14.8 (4.5)	16.0 (4.3)
Bar 4	18.6 (5.2)	16.5 (3.1)	**16.1 (2.2)**
Bar 5	19.5 (2.1)	18.9 (3.7)	17.7 (4.9)
Bar 6	11.9 (1.0)	**16.0 (4.6)**	14.2 (1.6)
Bar 7	**21.9 (3.2)**	17.9 (4.9)	22.8 (4.0)

Table 2. Percentage of incoming saccades for bars 2-7 (in %) across the three variations: means and standard deviations (in parenthesis) for the five participants. Note: The values for altered bars are bolded.

	Variation 1	Variation 2	Variation 3
Bar 2	1.8 (4.1)	1.5 (3.4)	2.9 (6.4)
Bar 3	16.8 (6.9)	17.2 (4.1)	23.3 (6.1)
Bar 4	16.8 (6.9)	17.2 (4.1)	**25.3 (6.4)**
Bar 5	17.8 (7.3)	24.2 (6.2)	13.1 (1.9)
Bar 6	24.9 (10.4)	**24.2 (6.2)**	17.6 (4.8)
Bar 7	**22.0 (11.0)**	15.6 (2.5)	17.9 (6.6)

C. Study 1: Summary

To sum up, the alterations from the familiar melody did *not* increase the relative fixation time for the target (i.e. altered) bars; instead, there was a relative increase of incoming saccades to the target bar and the bar preceding it. Thus, it appears that the unexpected modifications to the melody did result in re-adjustment of the visual processing, even if the hypothesis about allocating more time to unexpected events did not hold.

The pilot study revealed several problems in the experimental design, suggesting modifications for further studies. First, due to the size of the screen and the recording accuracy of the eye-tracking equipment, the melody had to be placed on two staves, which most likely caused its own effects for the visual processing. Second, in the third variation, the altered bar was near the end of the melody; in bar-specific analyses, the possible effects of the melodic deviation may have been mixed with eye-movement effects related to the expectation and observation of the final bar, considering that the final bar is visible within the perceptual span while the reader still fixates the notes in the preceding bar. Third, the data does not allow comparison to the original version of the melody. Fourth, applying a "natural" layout for the score resulted in slightly uneven sizes for the examined bars, which caused minor difficulties for the analyses of the eye-movement data. Fifth, appropriate statistical analysis of a larger pool of results would require a research design with a counterbalanced order of trials. These deficiencies were addressed in Study 2.

III. STUDY 2

The main aim of Study 2 was to statistically examine how unexpected melodic deviations from a familiar melody affect the allocation of fixation time and saccadic eye movements for musically experienced young adults. Based on the pilot study, we expected to find (i) no effects or only minor effects on the relative distribution of the fixation time and (ii) a relatively greater proportion of incoming saccades for the bars with an alteration and preceding the alteration.

A. Method

1) Participants. The original number of 40 participants was cut down by missing eye-movement or performance data for 6 of them; only the remaining 34 participants are discussed here and included in the analyses. The participants were (a) education majors (future elementary school teachers) minoring in music education at the Department of Teacher Education of a Finnish university (n = 21) and (b) students of music performance at a Finnish arts academy or conservatory (n = 13; including one participant who had completed her studies at the conservatory). The participants were between 19 and 37 years old (M = 26 years, SD = 5 years); 22 of them were females. Admission to both study programs necessitates passing program-specific tests of musicality and musical performance. All but one participant included the piano in their personal list of instruments; 20 reported the piano as their main instrument, and 23 had completed official (either elementary or professional) piano degrees. Participation was voluntary. The education majors received course credit for participation, and the performance majors were rewarded with a 10 EUR voucher to a student cafeteria.

2) Stimulus Materials. Variations 1 and 2 from Study 1 as well as the original version of "Mary Had a Little Lamb" were used as stimulus materials. The melodies were written with the Sibelius 6.2.0 music notation software. A 23" widescreen TFT monitor was used to present the melody in one horizontal staff while still maintaining a size comfortable for reading. The width of the staff on the screen was 31.3 cm (12.3 in), bars 2–7 being 3.8 cm (1.5 in; 143 pixels), bar one 5.1 cm (2.0 in; due to the clef and time signature) and bar eight 3.4 cm (1.3 in) in width.

Figure 2. The original melody of "Mary Had a Little Lamb" and Variations B (alteration in bar 4) and C (alteration in bar 6) as applied in Study 2.

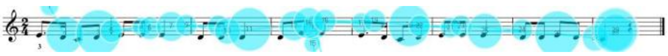

Figure 3. Variation B with one participant's fixations overlaid, as visualized by Tobii Studio 2.2.8. A fixation has landed on the exact center of each "bubble". The bubble size indicates the relative length of a fixation.

3) Apparatus. Eye movements during playing were recorded using a Tobii TX300 Eye Tracker manufactured by Tobii Technology AB (Stockholm, Sweden). Both eyes were tracked with a sampling rate of 300 Hz. The screen resolution was 1920 x 1080 pixels. A Yamaha electric piano and sequencer software (Power Tracks Pro Audio) were used to record the performances.

4) Procedure. The participants were tested individually in the presence of an experimenter (author MP). Each participant was first introduced to the laboratory setting and allowed to adjust the piano seat at a comfortable height. The experiment began with a familiarization phase in which the participant was first presented with the (original) notation of the melody "Mary Had a Little Lamb" on the computer screen and asked to perform it in time with a metronome set at 60 M.M., using the right hand only. This was followed by a practice phase with the purpose of introducing the participant to the research protocol. During this phase, the participant was presented with a series of written instructions followed by short, simple melodies (in C major; composed by author EH) on the computer screen while his/her eye movements and performances were recorded. Before each melody, the participant was instructed to look at a cross, marking the location of the first note two seconds in advance of the appearance of the staff. After the staff appeared, the participant was instructed to wait for two more beats (seconds) before initiating the performance. No chin rest was used in order to create as typical a performance situation as possible.

Finally, in the actual test phase, the participant was first informed that s/he would next perform four versions of "Mary Had a Little Lamb" in the tempo of the familiarization phase, and that some of the melodies would contain slight alterations to the original melody. The participant was asked to perform the melodies (two original versions of the piece, A1 and A2, and variations B and C: see Figure 2) as seen on the screen. The research protocol followed the procedure of the previous practice phase (see above). The order of the melodies was changed between every successive participant from A1–B–A2–C (Condition 1) to A1–C–A2–B (Condition 2). The assignment of the participants to one of the two conditions was quasi-randomized by allowing the participants themselves to book a time for their session.

5) Data analysis. A fixation was defined according to the default setting of Tobii Studio 2.2.8 (see Figure 3), with velocity and distance thresholds of 35 pixels/samples. Only fixations targeting the staff system were included in the analysis; thus, fixations beyond a 45 pixel distance from the staff were excluded. The limit was set exploratively with the goal of excluding clear outliers while including as many potentially task-relevant fixations as possible. With such a limit, in 99.3% of the 34 x 4 trials, at least 70% of the fixations occurring between the first and last MIDI note onsets fell within this visual area, and, in 72.8% of the trials, at least 90% of them fell within the area. The outlier fixations would be – in our interpretation – either glances beyond the screen or fixations performed before or after a participant glanced at his/her fingers.

Similarly to the pilot study, bars 2 to 7 were included in the actual analyses. To calculate all the necessary measures, fixations between the timestamps of the first note onsets of bar 1 (E4) and bar 8 (c1) were examined. It was required that the first note onset of bar 1 was, in all cases, the beginning of the actual performance. Similar-sized AOIs around each bar were defined according to the x-coordinate values of the bar line. Each fixation was then assigned to one of the resulting one-bar AOIs according to its own x-coordinate value.

In the data set of the sequencer-recorded keyboard performances, the total 1088 performed bars included only 12 bars (10 target bars) with one or more performance errors (performed by 9 different participants). Due to the negligible amount of errors, their eye-movement effects were considered insignificant, and thus not regarded in the following analyses.

B. Results

1) Allocation of Fixation Time. Relative fixation time allocated to bars 2-7 in each of the four melodies was calculated for all participants. First of all, comparing the average relative bar-specific fixation times within one melody, a series of independent samples *t*-tests did not differentiate the two conditions. Secondly, comparing the two participant groups in a similar analysis, only fixation time allocated to bar 6 in the Original A1 differed between the groups ($M = 12.7$ % and $SD =$ 2.4 % for education majors and $M = 14.9$ %, $SD = 3.3$ % for performance majors; $t(32) = -2.285$; $p < .05$), leaving a total of 23 bars with non-significant differences. Thus, the two conditions and the two participant groups were combined for the following analyses.

The relative fixation times allocated to bars 2-7 in the four melodies were then compared, bar by bar, with one-way ANOVA analyses (see Table 3). Significant differences between the melodies were here found in the fixation times allocated to bars 4 and 5 ($F(3, 135) = 3.076$, $p < .05$ and $F(3, 135) = 7.855$, $p < .005$, respectively). More specifically, according to a Tukey's HSD test, a smaller proportion of fixation time was allocated to bar 5 in Variation B than in any other melody (comparing to A1: $p < .06$; A2: $p < .005$; and C: $p < .005$). In addition, in Variation B, significantly more time was allocated to the altered bar 4 than was the case in the Original A1 ($p < .05$). No similar effect was found for Variation C in which the altered bar appeared closer to the end of the melody.

2) Incoming Saccades. Analogously to the above bar-by-bar analysis of relative fixation duration, we also examined the bar-by-bar percentages of incoming saccades (see Table 4). First, in comparing the average bar-specific percentages within one melody, a series of Mann-Whitney *U*-tests did not differentiate the two conditions, with the single exception of bar 2 in Variation C ($M = 14.5$, $SD = 5.2$ for condition 1 and $M =$ 7.2, $SD = 7.1$ for condition 2; $U = 60.0$, $Z = -2.938$; $p < .005$). Second, when the two participant groups were compared in a similar vein, no significant differences emerged. As above, then, we could combine the two conditions and the participant groups for the following analyses.

Table 3. Relative fixation time for bars 2-7 (in %) in the four performed melodies: means and standard deviations (in parentheses) for the 34 participants. Note: The values for the altered bars are bolded.

	Original A1	Original A2	Variation B	Variation C
Bar 2	13.7 (3.2)	12.9 (3.1)	13.0 (3.6)	12.3 (3.2)
Bar 3	14.5 (2.4)	14.7 (4.0)	15.5 (2.8)	14.0 (2.9)
Bar 4	16.5 (3.5)	17.1 (3.7)	**19.0 (3.5)**	17.1 (3.9)
Bar 5	18.8 (3.7)	19.8 (4.4)	16.3 (3.8)	20.8 (4.2)
Bar 6	13.5 (2.9)	13.1 (3.6)	13.1 (3.6)	**13.7 (3.6)**
Bar 7	23.0 (5.1)	22.5 (5.8)	22.8 (4.4)	22.1 (4.6)

Table 4. Percentages of incoming saccades for bars 2-7 (in %) across the four performed melodies: means and standard deviations (in parenthesis) for the 34 participants. Note: The values for the altered bars are bolded.

	Original A1	Original A2	Variation B	Variation C
Bar 2	11.7 (7.8)	10.9 (8.3)	14.4 (7.3)	10.6 (7.2)
Bar 3	16.3 (4.2)	19.1 (6.3)	20.3 (5.6)	17.2 (4.7)
Bar 4	17.8 (4.7)	18.3 (7.0)	**17.1 (6.4)**	19.7 (5.8)
Bar 5	16.6 (4.4)	17.0 (6.1)	14.2 (4.6)	20.5 (5.7)
Bar 6	17.5 (5.0)	17.8 (5.2)	16.9 (5.9)	**18.5 (6.3)**
Bar 7	20.1 (6.2)	16.8 (6.5)	17.1 (7.4)	13.4 (4.3)

A Kruskal-Wallis analysis was administered to compare, across the four melodies, the relative distribution of incoming saccades targeting each bar. The analysis revealed that the percentages of incoming saccades at bars 3, 5, and 7 differed significantly between the four melodies ($\chi^2(3) = 10.640$; $p < .05$, $\chi^2(3) = 21.391$; $p < .0005$ and $\chi^2(3) = 20.063$; $p < .0005$, respectively). Pairwise comparisons for bars 3, 5, and 7 were then conducted with a series of Mann-Whitney *U*-tests. The first overall conclusion from these analyses is that the bar *before* the melodic alteration tended to collect a higher amount of all incoming saccades compared to the corresponding bars in the other three melodies. Variation B (bar 3) differed in this respect both from Original A1 ($U = 332.5$, $Z = -3.033$; $p < .005$) and from Variation C ($U = 389.5$, $Z = -2.325$; $p < .05$), and Variation C (bar 5) differed likewise from all of the other melodies (A1: $U = 357.5$, $Z = -2.730$; $p < .05$; A2: $U = 377.0$, $Z = -2.477$; $p < .05$; B: $U = 218.0$, $Z = -4.444$; $p < .0005$). Second, it also seems that the bar *after* the melodic alteration received relatively low percentages of incoming saccades. Thus, Variation B (bar 5) differed in this respect from Original A1 ($U = 381.5$, $Z = -2.437$; $p < .05$) and Variation C (bar 7) differed almost significantly from all of the other three melodies (A1: U = 201.0, Z = -4.653; $p < .0005$; A2: U = 399.5, Z = -2.198; $p < .05$; B: U = 420.5, Z = -1.945; $p < .06$). (In addition, bar 7 showed significant differences between A1 and A2 [U = 413.0, Z = -2.031; $p < .05$] as well as between A1 and B [U = 384.0, Z = -2.390; $p < .05$], but these cannot be interpreted with a reference to the altered bars.)

C. Study 2: Summary

The melodic alterations to the familiar melody were found to affect both the relative fixation times and the distribution of incoming saccades. Neither of these effects was observed for the altered bars themselves, however, but only for the bars around them. First, in particular, there was *no* increase of relative fixation time at the “unexpected” bars. Instead, when the melodic alteration was embedded in the middle of the melody in Variation B, it had the effect of decreasing the relative fixation time allocated to the immediately *following* bar. That a similar effect did not occur in Variation C could be accounted for by the fact that here the bar in question was the penultimate bar of the melody which in all four melodies accumulated around 22–23% of the relative fixation time available.

Second, the altered bars generally had the effect of increasing the proportion of incoming saccades to the bars before them, which is in line with the pilot experiment above. Again, however, no effect was found at the altered bars themselves, but the immediately following bars showed a decrease in the relative amount of incoming saccades.

IV. GENERAL DISCUSSION

The aim of the current studies was to take some steps toward exploring the eye-movement processing associated with unexpected melodic events when these occur in a temporally constrained music reading task. In both of the two studies, participants performed variations of the well-known tune “Mary Had a Little Lamb” on an electric piano in a set tempo and with the right hand only. Eye movements during music reading and piano performances were recorded.

The pilot study (Study 1) conducted with five experienced amateur musicians suggested that unexpected melodic events may primarily increase the number of saccades targeting the unexpected event itself as well as the immediately preceding visual area in the score. After some improvements in the research design, we conducted the main experiment (Study 2) in which 34 musically experienced participants performed the original version of the above-mentioned piece as well as two of the variations created for the pilot study. The data were examined statistically. The most obvious eye-movement effect of unexpected melodic events appeared when the alteration occurred in bar 4: In bar-specific analyses the altered bar affected the incoming saccades and fixation times, increasing the proportion of incoming saccades to the bar before the altered bar, and decreasing the relative fixation time and the proportion of incoming saccades for the bar following the altered bar. When the alteration occurred later on in the melody, in bar 6, similar findings emerged concerning the proportion of incoming saccades.

These findings suggest that during the performance of a familiar melody, an altered bar may indeed function as a disruptive element, resulting in local adjustments of the performers’ visual processing. However, such changes were not realized as a direct increase of relative fixation time for the altered bar itself, as might have been expected on a direct analogy with local problems encountered in text reading (cf., e.g., Just & Carpenter, 1980; Rayner, Warren, Juhasz, & Liversedge, 2004; see also Madell & Hébert, 2008). In our temporally controlled tasks, the effects were rather manifested as the lessening of fixation time for the bar after the altered one. We suggest that the reason for this lies in stimulus-driven local adjustments to the eye-hand span. After these promising first results, we will in future look further into this matter by synchronizing the eye-movement and performance data.

The two studies presented in this paper demonstrate an attempt to control the research design with the strictness customarily seen in eye-tracking research within other domains, while still presenting a musically meaningful task to the participating musicians. Specific emphasis was placed, first of all, on achieving a music-reading task that would place the performer in a true sight-reading situation. This was accomplished by creating unforeseeable but visually non-salient alterations within a familiar melody and allowing the participants only minimal (2 s) time for preparation before each trial. The choice of stimuli was based on the assumption that familiarity with the original melody might actually highlight the eye-movement effects caused by the unexpected and sight-read musical material, compared to a completely unknown melody containing, for example, tonally surprising and thus more or less unexpected melodic patterns. In addition, as the variations repeated the rhythmic patterns of the original melodies and the participants were able to rely on their prior knowledge on the melody on that aspect of the reading process, the eye-movement effects can be explained with reference to the *melodic* deviations.

A second point of emphasis was relying on metronomically controlled performances for a better grasp of the temporal dynamics of eye-movement processing in the face of unexpected stimuli. This was facilitated not only by the use of the metronome, but also by selecting skilled participants, and letting them accustom themselves to the tempo by initial practice with the original version of the piece. Given the simplicity of the tasks for our skilled participants, manifested in the virtually flawless performances of the children’s song they produced, the systematic eye-movement effects appear all the more striking. While only scratching the surface of the multifaceted phenomenon of melodic expectations, the two studies nevertheless indicate an interesting prospect for future studies: eye-tracking methodology might allow us tap even such aspects of the musical performers’ cognitive processes which do *not* result in clear audible effects, say, in the form of mistakes or expressive deviations. Eye movements reveal how even seemingly trivial modifications of simple notated music do affect the zero-sum game of allocating fixation time to a score that is to be played as music most often is – in tempo.

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