Gaze Patterns of Skilled and Unskilled Sight Readers Focusing on the Cognitive Processes Involved in Reading Key and Time Signatures

J. F. Viljoen, Catherine Foxcroft

Abstract**—**Expert sight readers rely on their ability to recognize patterns in scores, their inner hearing and prediction skills in order to perform complex sight reading exercises. They also have the ability to observe deviations from expected patterns in musical scores. This increases the "Eye-hand span" (reading ahead of the point of playing) in order to process the elements in the score. The study aims to investigate the gaze patterns of expert and non-expert sight readers focusing on key and time signatures. 20 musicians were tasked with playing 12 sight reading examples composed for one hand and five examples composed for two hands to be performed on a piano keyboard. These examples were composed in different keys and time signatures and included accidentals and changes of time signature to test this theory. Results showed that the experts fixate more and for longer on key and time signatures as well as deviations in examples for two hands than the non-expert group. The inverse was true for the examples for one hand, where expert sight readers showed fewer and shorter fixations on key and time signatures as well as deviations. This seems to suggest that experts focus more on the key and time signatures as well as deviations in complex scores to facilitate sight reading. The examples written for one appeared to be too easy for the expert sight readers, compromising gaze patterns.

Keywords**—**Cognition, eye tracking, musical notation, sight reading.

I. Introduction

EYE tracking technology has provided researchers with specific tools to empirically study the process of reading (language and music) over the last decade.

Music sight reading can be broadly defined as reading a musical score, conceptualizing it and performing at the same time [1]. The music being read is therefore realized in real time. This adds a temporal component to the reading aspect, not often found when studying reading language text. In short, once a performer starts playing, the temporal element of music prevents him or her from stopping as this would disturb the natural flow of the music.

The information found in musical scores presents the reader with both a pitch and duration element in each symbol [7]. Both of these features of notation have to be processed in order to perform a note correctly. Another complexity in sight reading is the presence of a motoric component [3]. This component occurs because the visual cues need to be translated into physical movements to be performed on any given instrument.

Initial studies theorize that music sight reading is a "genuine species of music perception" [9]. Early studies done by [4], focused on the perceptual span (the region of visual stimulus that can be seen during a single fixation) [7]. These early studies helped classify eye movements into fixations and saccades. Fixations are defined as short static gaze points (where the brain gathers information) while saccades are rapid movements between these static points (where the brain processes information) [7]. According to [10], three main skills are needed in order to gain expertise in sight reading; pattern recognition, prediction skills and inner hearing.

Research focusing on eye movements during sight reading has found that expertise seems to reduce the number of fixation durations and increase fixation frequency [6]. Huovinen et al. [5] further claim that expertise could determine how far the eyes are ahead of the performance at any given moment. This phenomenon has come to be known as the "Eye-hand span".

Expert sight readers appear to possess the ability to group or chunk details in a musical score into recognizable groups or patterns [1]. This seems to be as a result of extensive and structured knowledge of the element being read. These patterns appear to be organized in a hierarchical order [2]. Expertise in sight reading can therefore be defined as skilled pattern recognition [11]. Expert sight readers also possess the ability to spot errors in a musical score [1], [11]. These errors or deviations from expected musical patterns increase the "Eye-Hand Span" of expert sight readers [5].

Previous research explores sight reading focused on general differences in reading strategies of expert and non-expert readers. Most of these studies investigate the "Eye-Hand Span", but do not include specific elements of the score and how these are processed. In her review of sight reading studies, Puurtinen [7] suggests that future research should explore these specific elements of musical notation when performed in real time.

Aims

This study aims to investigate the cognitive underpinnings of key and time signatures in the reading of musical notation. While much of the research utilizing eye tracking focuses purely on the "Eye-hand span", this study aims to study the gaze patterns centered on key and time signatures. Accidentals and changes of time signatures were added to the musical examples in order to study the fixation duration and

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fixation counts involved in reading these elements.

II. Method

Two selected aspects of music notation, key and time signatures were the main focus of the study. To investigate these aspects, research participants were provided with 17 sight reading examples for one and two hands. These were composed specifically by the researcher. These examples were written in varying keys ranging from C major (no flats or sharps) to five sharps or flats. Time signatures were limited to 4/4, 3/4, 2/4 and 2/2. In order to study the cognitive processes involved in reading key and time signatures, some examples included either accidentals or changes of time signature as deviations to expected patterns. A few examples were added without any deviations to further test this effect.

The sight reading examples are summarized in Table I.

TABLE I
Keys and Deviations Used in Sight Reading Examples

	Key	Accidentals added	Changes of Key Signature
Example 1	C major	0	0
Example 2	G major	1	0
Example 3	B-flat major	0	2
Example 4	A major	2	0
Example 5	D major	0	4
Example 6	D-flat major	2	0
Example 7	E-flat major	0	1
Example 8	E major	2	0
Example 9	F major	0	4
Example 10	A-flat major	3	3
Example 11	G major	0	0
Example 12	F major	0	0
Example 13	B-flat major	2	0
Example 14	E major	5	0
Example 15	B major	0	2
Example 16	D-flat major	1	3
Example 17	C major	0	0

All examples were performed with a metronome set at 60 crotchet beats per minute. This was done to ensure that all participants performed the examples under the same temporal conditions [8]. Puurtinen also argued that using simple melodies to test eye tracking could be criticized for being too simple, but “in the end one can argue with more certainty what one’s findings might mean and what their cause might be” [8]. This study therefore included examples of a simple nature for one hand. A second test was included containing slightly more complex examples for two hands. These were added to study how participants would cope with sight reading more akin to what they would find in practice.

Tobii eye tracking equipment and software were used to record the eye movements of twenty participants. The participants were piano teachers from Port Elizabeth and Makhanda as well as piano students from two universities in South Africa. Each participant was required to have a minimum piano qualification of Grade 6 from any standard examining body in order to participate. This method of classification was used in an earlier study [1]. In this study, each participant performed a Grade 6 piano sight reading exercise from the Trinity College London syllabus in order to determine which group they would be assigned to. The A group consisted of 11 experienced sight readers, with an average age of 40. The B group consisted of nine inexperienced sight readers with an average age of 27.

Each participant was presented with 17 sight reading examples, 12 for one hand (Test 1) as well as five for both hands (Test 2). The examples for one hand were presented to each participant in a random order. This was followed by the examples for two hands, also presented in a random order. The sight reading examples consisted of eight bars set out in three lines. Fig. 1 shows Example 13 used in the study. All examples were performed on a standard full-size electronic keyboard. These examples were projected on a 19” LCD computer monitor in landscape orientation. The computer monitor and the eye tracker were both mounted on a height-adjustable stand to facilitate different heights of participants.

Fig. 1 Example 13

Participants’ gaze patterns were recorded using the Tobii Pro X2-60 Hz eye tracker using Tobii Studio Software. Through tracking participants’ gaze patterns (a recording of location and duration of fixations), participant responses to the key signature, time signature as well as all unexpected deviations were recorded and analyzed by the Tobii Studio software. The time and key signatures of each example as well as any unexpected elements were selected as areas of interest. The fixation duration (how long each participant fixated) in each area of interest for both participant groups was compared. Fixation counts (the number of static fixations in which the brain absorbs information) for both participant groups were also compared.

III. Results

The Tobii Studio Software was used to isolate areas of interest. These are selected by creating a box on the score to include the information required. The key and time signature was selected in each example as the first area of interest. The vertical length of the box matched the height of the treble clef.

Each accidental and time signature change was also selected as an area of interest. Fig. 2 shows Example 13 with all areas of interest.

A. Fixation Count

The fixation count (number of fixations) was recorded for both participant groups for all areas of interest selected. These included the key and time signature at the start of each example as well as any deviations added to the examples. The results for the average fixation count in all the areas of interest were compared for both groups. These results can be seen in Fig. 3. All measurements were taken in seconds.

Fig. 2 Example 13 with areas of interest selected

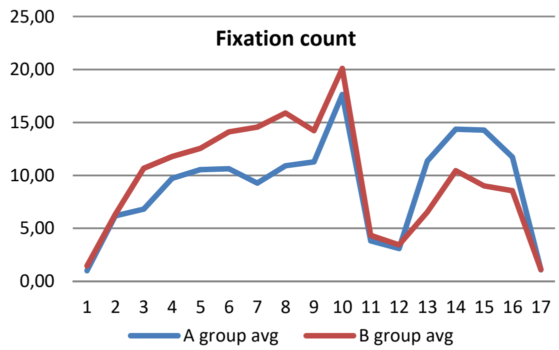

Fig. 3 Fixation count scores for Groups A and B

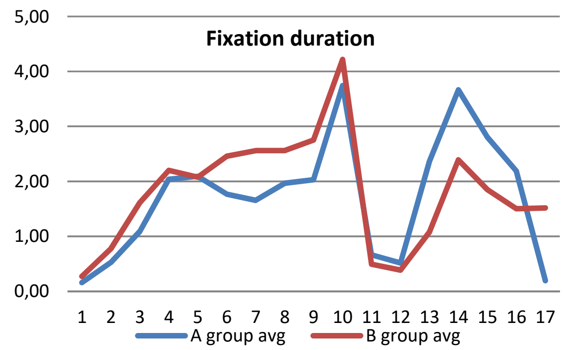

Fig. 4 Fixation duration scores for Groups A and B

The results show a higher fixation count for the examples composed for one hand in Group B than Group A. This is contrary to findings in previous studies. The examples for two hands yielded a consistently higher fixation count for the A group. This appears to support the current body of research.

All participants were sent a review questionnaire after data collection. Some experts remarked that the one-handed sight reading examples were too easy and allowed them time to look around the room and not at the screen. This could account for the lower fixation count depicted in the scores.

Fixation Duration

The fixation duration for each participant was recorded for all of the areas of interest selected. These included the key and time signature at the start of each example as well as any deviation that was included in the examples. The results were compared between the A and B groups. The fixation duration for all other areas of the score was also recorded and compared between the two participant groups. The results for the average fixation durations in the areas of interest for each example were compared and can be seen in Fig. 4. All measurements were taken in seconds.

The results were similar to the fixation count. The B group scored higher in the areas of interest compared to the A group. This could be a result of the expert group finding the examples composed for one hand too easy. If non-expert sight readers spend time focusing on every note in succession, then the fixation duration could exceed that of the expert group who only focus briefly on important elements in the score. This could account for the higher fixation duration in simpler examples.

The opposite result was found in the examples composed for two hands. Here the expert group focused more in the areas of interest than the non-expert group. It could be that their "Eye-hand span" is increased in order to process the key and time signatures as well as the deviations in the score. The non-expert group simply seemed to continue focusing on individual notes instead of grouping them together into patterns.

Gaze Patterns

The heat maps for each group were collected for every example. This depicts the location and estimated duration of all fixations for every example. Figs. 5 and 6 show the heat maps of Example 13 for the A and B groups. It illustrates the group gaze plots for the example. The green areas are short fixations. The color intensifies towards red as the fixation duration increases.

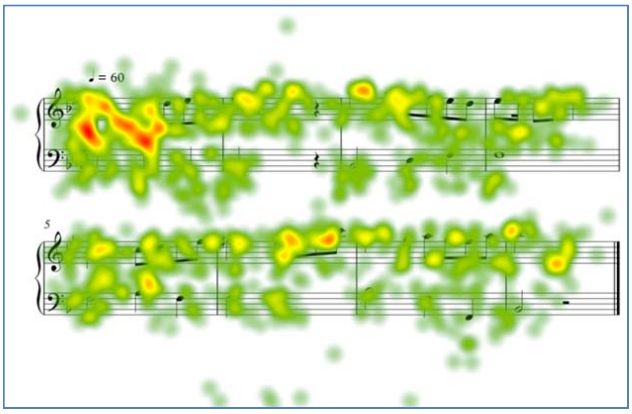

Fig. 5 Heat map for Example 13 for Group A

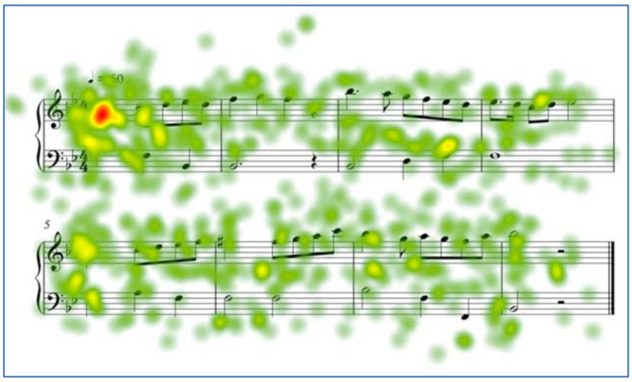

Fig. 6 Heat map for Example 13 for Group B

The A group’s gaze patterns appear to be more uniform than the B group. They are generally more focused on the stave, with a few exceptions at the bottom of the screen. This could be explained by the experts looking down at their hands while playing. The longest fixation durations (red fixations) are mostly focused around the areas of interest and sections of the music that are more complex. The B group on the other hand showed significant fixation duration on the key and time signature at the start of the piece but very little for the rest of the score. There were also numerous fixations not focused on the stave or notes and fixation patterns appear more haphazard than the expert group.

IV. Discussion

The study aimed to investigate the gaze patterns for expert and non-expert sight readers when responding to elements like key and time signature and unexpected changes in the score relating to these images. One of the difficulties encountered when designing this study was creating sight reading examples at a level that could be successfully performed by all participants. A number of original participants had to be discarded because they could not perform the examples with the required metronome beat. It was theorized that the examples for one hand would solve this problem, while the examples for two hands would test both non-expert and expert sight readers alike on their abilities.

In hind-sight, the examples composed for one hand were perhaps too easy for the expert group and yielded results that are contrary to previous research [5]. Some of the experts’ responses indicated that they had ample time to look around instead of focusing on the musical score. These examples yielded consistent results for both fixation count and fixation duration.

The examples composed for two hands appear to yield more usable results. Here both groups were tested under more natural conditions, forcing the expert group to utilize the reading skills described in previous research. The non-expert group yielded very low scores for both fixation count and duration, as they appear to have attempted to perform the examples by focusing on every note. Future research could perhaps focus more on musical scores for both hands, as these seem to provide a better stimulus for expert readers.

V. Conclusion

The results seem to suggest that experienced sight readers focus more on the key signature, time signature and deviations in the score in complex music to facilitate real time sight reading. This is not the case for inexperienced sight readers, who focus on every note in succession. These findings suggest that a sound musical knowledge (like the ability to group elements into patterns, predicting or using inner hearing) may play a positive role in performers’ sight reading skills.

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