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A Comparison of Saccadic Eye Movements Made by Musicians When Reading Music Versus Text

ABSTRACT

The intent of this preliminary study was to determine the difference in the number of saccadic eye movements between reading music and reading text, thereby indirectly measuring the difference in visual demand between these two tasks. We used the Eye Trac to measure the number of saccades made by keyboard musicians while reading standard Eye Trac text and while reading musical notes. The musical text was written to stimulate the visual and cognitive demands of the Eye Trac text as closely as possible. Graphical and statistical analyses were performed on the data. The mean number of saccades per second was greater for reading music (5.032) as compared to reading text (3.529), and the overall times required to complete each task also were very different (16.4 seconds for text, 120 seconds for music). These differences were statistically significant.

KEY WORDS

fixations, regressions, saccades, return sweeps, music sight reading, eye-hand span, text reading

There is a well known saying that music is the universal language and is the one medium common to all people. Despite the universality of this media surprisingly little is known about the motoric (eye movements) and cognitive processes that go on during the playing and listening of music. As one of the few authors on this subject states, "The question of how we study and understand such processes has not really been addressed by mainstream contemporary research."[1]

Optometrists are concerned with the visual demands that various tasks require of their patients. Information obtained about their occupations, hobbies, and overall visual needs yields essential information for prescribing lenses or other modes of treatment that will enhance their comfort and productivity. But the visual demands of musicians, and specifically the oculomotor demands involved in the task of reading music, are topics that have largely been ignored by contemporary research in vision science.

The task that is most similar to reading music is reading text, and there is a wealth of information in the literature concerning the eye movements made during the reading task. In contrast, there is a paucity of published reports on eye movements made during the reading of music. The research concerning this topic is still in its infancy. An understanding of the eye movements that take place during the task of reading music will help us to better understand the unique visual demands of the musician. This in turn offers the potential to provide the musician with an enhanced quality of eye care.

DEFINITIONS

The major eye movements that have been identified during the reading of text and music are:[2]

Fixations

These are reflex movements which maintain the image of a stationary object upon the fovea. It is during the fixation that visual and cognitive information about an object or text is extracted. The time spent during fixations occupies approximately 90 percent of one's total reading time.

Saccades

These are high velocity, all-or-none movements that move fixation to a new point of interest in the visual field. Saccades immediately follow fixations during reading and serve to allow sequential visual input of the written text.

Regressions

These are saccades that move in a right-to-left direction (opposite that of the normal direction of reading English). They are the motoric component of the individual's attempt to reanalyze contextual information that has been missed.

Return Sweep

These are large right-to-left movements that shift the point of gaze from the extreme right end of a line to the beginning of the next.

Sight Reading

This is the reading and playing (singing) of an unfamiliar piece of music.

Eye Voice Span

This is defined as the number of words a subject will read beyond the point where the text is suddenly covered.[2]

Eye Hand Span

This is defined as the number of notes that a subject will play beyond the point of where the music is suddenly covered. This is a comparable measurement to the Eye Voice Span and is a measure of how far ahead in the music the musician is reading.[3]

VISUAL PROCESSES INVOLVED IN READING TEXT

The number of letters that can be seen during a given fixation is termed the *Perceptual Span* and has been measured as approximately 18 letters.[4] The Span is asymmetric about the point of fixation and averages three to four letters to the left of fixation, and 12 to 15 to the right (for readers of English).[5] Within the Perceptual Span there is a foveal "cone" of clear vision that covers five to eight letters at one time, termed the *Semantic Span.*[4] These are the letters the individual can directly identify, extract information from, and cognitively process. The remaining letters in the parafoveal region occupy an area termed the *Span of Useful Information.*[6] Because visual acuity drops in the parafoveal zone, meaning cannot be directly accessed from these letters; however, information about word length and shape can be obtained, which helps the reader to anticipate the upcoming text. This information is used, along with foveal information on text complexity, to determine the next saccadic amplitude and the next point of fixation. Parafoveal information is essential for smooth eye movements and rapid reading, and studies have shown that without these clues the foveal scanning speed dramatically decreases and the durations of fixations become significantly longer.[5] The current literature suggests that overlapping fields of visual information are processed during the task of reading; words in the foveal region are directly identified, and those in the parafoveal region are indirectly identified or anticipated according to visual information about word length and shape.[2]

VISUAL PROCESSES INVOLVED IN READING MUSIC

The most elemental forms of reading music are based on four clues: the *Exact Position*, the *Approximate Position*, the *Absolute Contour* and the *Relative Contour* of the notes[7] (see Figure 1). The Exact (vertical) Position defines where the notes lie in the musical staff. The notes in this instance lie within the foveal cone of vision. The parafoveal zone to the right of fixation is where the remaining three clues are accessed. Musicians cannot directly identify notes in the parafoveal zone, but they can extract information about their Approximate Position in the musical staff. For example, a musician cannot directly identify a B note, but he can assess its approximate position and know that it will probably be either an A, B or C note that must be played. The Absolute Contour gives information about the vertical relationships between notes. Before a musician determines the Exact Position of a note, the Absolute Contour gives him clues about which direction, either ascending or descending, the music is going to take. The Relative Contour requires at least three notes, and it aids the musician in identifying ascending or descending passages, or directional changes within the music. Many times a phrase or sequence within the music ends with a change of direction, and Relative Contour enables the player to anticipate when to pause or give emphasis to a note(s). Relative Contour is the most global clue used by the musician. Finally, on a higher cognitive level, studies have shown that experienced musicians can identify specific musical structures and patterns as they play (e.g., dominant chords, arpeggios)[1] that are used to anticipate the upcoming musical text.

STUDIES ON EYE MOVEMENTS WHILE READING MUSIC

There have been nine studies performed to date that have attempted to measure the eye movements of musicians. The majority of these studies were performed by graduate students and professors of music who were interested in identifying the oculomotor skills that separate superior from poor sight readers. The emphases of each of these studies, their methods of evaluating the eye movements, and their conclusions varied greatly. The ultimate goal of many of these studies was to develop methods of training sight reading in music students.

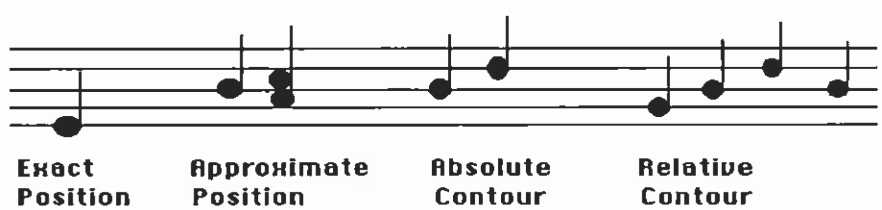

Figure 1. Basic Clues for Reading Music. The four clues that form the basis of reading music are illustrated in this diagram. From left to right these visual clues are the Exact Position of the notes, as accessed in the foveal cone of vision; the Approximate Positions of the notes--in this instance the approximate notes around a B note; the Absolute Contour, or the vertical relationships between the notes; and the Relative Contour, which warns the musician of a change of direction. The latter three clues are accessed in the parafoveal zone to the right of fixation.

These studies used various methods, including the Ophthalmograph, motion picture cameras and computerized motion detectors, to record eye movements. They all reported the same horizontal eye movements that have been observed in studies of reading text.[8,9] They also reported saccades of a diagonal and vertical nature, which are unique to the task of reading music. These saccades correspond to the vertical displacement of the notes along the musical staff. Early studies[9,10] concluded that piano players read notes in a descending fashion from the treble line to the bass line. Young[3] found that the better musicians fixate the middle of a chord and then make multiple fixations up or down the chord, eventually ending in the bass staff. She also discovered that her subjects made multiple previewing and reviewing fixations around a chord or note. Lang[8] calculated that his subjects made converging movements of up to 6 prism diopters as fixation moved down the musical staff. Weaver[9] investigated whether different styles of music gave rise to more horizontal or vertical saccades, and concluded that diagonal patterns were more dominant for the contrapuntal style as compared to melodic or chordal styles of music (which gave rise to more horizontal eye movements).

All of these studies reported differences in the eye movements between skilled and poor sight readers. Several studies concluded that poor sight readers make a larger number of fixations and regressions,[10,11] similar to the conclusions obtained in the studies of reading text. Lang[8] felt that the poor sight readers were those who made too many or too few fixations. Successful sight readers were those that had a good balance between the number and durations of fixations, and the demands of the particular music they were playing. Young[3] found that good sight readers made more reviewing fixations (regressions), fewer previewing fixations, and, overall, more total fixations than did the poor sight readers. Jacobsen[10] found that the duration of fixations were longer for poor sight readers. Both Lang and Weaver[8,9] stated that there must be extensive overlapping of the fixation fields in order for a subject to be a successful sight reader.

It has been reported that the complexity of written material affects the number and duration of eye movements.[2] These same relationships have been reported in studies of reading music. Several demonstrated that the number of fixations increases with the difficulty of the music.[8,10] Halverson[12] concluded that the duration of the fixations decrease with an increase in complexity of the music, but York (as reported by Schmidt)[11] found the opposite. Schmidt[11] found a decrease in the duration of regressions, but none of the authors reported a significant change in the number of regressions associated with an increase in music complexity.

The measurement of the Eye Hand Span is relevant to the study of eye movements because musicians are trained to read ahead in the music as far as possible, i.e., to develop a large Eye Hand Span. Three of the previously cited studies found that skilled sight readers have significantly larger Eye Hand Spans than poor sight readers.[9,10,11] Weaver[9] and Young[3] felt that the span varied between individuals and varied constantly with changes in the complexity of the music. Young measured the average Eye Hand Span to be 1.3 notes ahead of those being played. Halverson[12] concluded that the Eye Voice Span (of singers) decreased as the complexity of the music increased.

Several of the previous studies compared the eye movements made during the reading of text versus the reading of music. Three[8,11,12] concluded that the average number of words was equal to the average number of notes per pause (fixation) if no tempo was introduced. Others[11,12,13] concluded that the fixation duration was longer in reading music versus reading text. Ortmann[14] found that the visual spans were essentially the same between the two tasks. Lang[8] found that the reading rates and the average time for interfixation movements were both 33% faster for reading prose. His data demonstrated a strong correlation between those subjects who were poor readers of text and those who were poor sight readers. Based upon this finding, Lang concluded that one should be able to identify a deficiency in sight reading ability by means of a battery of (text) reading tests, but this has been challenged.[3]

METHODS

The purpose of our study was to compare the number of saccadic eye movements when subjects read text and music. Our hypothesis was that there would be a significantly greater number of saccades when the subjects read and played the musical selections. This was based upon the conclusions of earlier studies[8,11,12] that musical notes were equivalent units to words in the visual span.

We used the Eye Trac (Model 106, available from G & W Applied Science Labs) to measure the number of saccades. The Eye Trac is a biometric device that focuses a beam of infrared light on the nasal and lateral limbal areas of each eye. The light reflected from the two beams is measured by two corresponding receptors. Any difference between them, which is generally due to an eye movement, causes a current to be generated, thereby causing a horizontal deflection of a recording pen on a sheet of graph paper. The Eye Trac is limited to measuring only horizontal eye movements.

Our subject population consisted of nine subjects, five females and four males, all non-presbyopes, whose ages ranged from 26 to 34. Subjects were chosen among the college and graduate students of Pacific University. They were required to have binocular 20/20 best corrected near vision (40 cm) and to have at least two years of experience on the keyboard (as determined by case history). All of the subjects fit this criteria.

Standard protocol was followed for measuring the eye movements with the Eye Trac instrument. Once the subjects were properly aligned they were asked to silently read the selection of text (see Figure 2). We recorded their eye movements as they read. The subjects were asked to read at a comfortable pace and to pay attention to the context of the piece. After the subjects completed reading the selection they were given a short standardized quiz to determine the level of comprehension. The eye recordings were judged to be invalid if a subject had greater than a 40% error rate on the quiz of this third-grade level text.

Subjects were then realigned in the Eye Trac and were asked to sight read a short piece of music that was written by the authors (see Figure 3).

The subjects performed the music on an electronic keyboard that was comfortably positioned to their right. The music was written for the right hand only. They were asked to play the piece at a comfort-

Reading Task

Susan likes to listen to music. She has over fifty records to play on her record machine. Most of her records are songs, but some tell stories. After school, Susan plays records for her friends. She keeps her records on a shelf above the record machine. She is careful never to scratch them with the needle. Susan has broken only one record.

Figure 2. Third-Grade Level Text Target

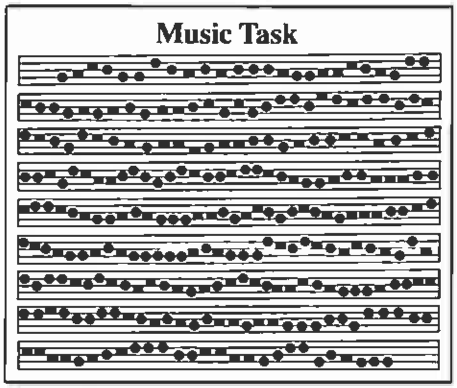

Figure 3. Music Target

able tempo, and to listen for a number of well known melodies. These (four) melodies were written into the music and separated by randomly chosen notes. A short quiz on the melodies was given after completion of the piece to again determine the level of context comprehension. A 40% error rate on the musical quiz was initially used to be a sign of invalid eye measurements.

All attempts were made to make the visual and cognitive demands of the musical task equal to that of the Eye Trac text card. The music was written in such a way that:

1. The number of notes per line equaled the number of letters per line. The total number of notes equaled the total number of letters.
2. Average horizontal width of the letters was calculated to be two millimeters. The notes were written with an identical circumference, so the visual angles of the two tasks were equal. The Snellen demand for the letters and notes was estimated to be 20/80.
3. Average vertical distances between the notes and letters were written to be as equal as possible. A limiting factor was that the nature of musical notation necessitates changes in vertical placement within the staff.
4. To simplify data collection, the music was written with no measure bars, no tempo or key signature information, and no change in length of the notes (they were written as quarter notes). The distance between the corresponding notes in the musical text were large enough for the Eye Trac to discriminate between fixations and saccades.
5. Because written and musical languages are so different it is difficult to determine if the cognitive demands for the two tasks were exactly equal. To give an approximation of the cognitive demand of the Eye Trac text, the musical piece was written to be played by *one hand only*. The piece could easily be played by a musician who had three to six months of experience on the keyboard. Third-grade text is very simplistic and we assumed the cognitive demands between the musical and reading tasks, especially when performed by students reading at the college level and experienced musicians, to be approximately equal. The determination of the number of saccades and fixations on the Eye Trac tape is a simple process. Vertical lines correspond to fixations (i.e., when the eye is not moving) and horizontal lines correspond to saccades (with the tape oriented vertically). The deflection on the tape is opposite that of the eye movements.

The total number of saccades made during the reading of the text were counted and recorded. This number was divided by the total time to obtain saccades per second. Because there were so many saccades involved in reading the musical text, a calculation was made to estimate the total number. The speed of the tape in the Eye Trac is one centimeter per second. The number of saccades were counted in three to four different blocks of four centimeters each, and the means were calculated. This number was divided by four to obtain the average number of saccades per second. The time it took the subject to play the piece was also recorded. The indices of variability were calculated and a one- tailed (directional) T test was performed. The T test compared the mean number of saccades for reading music and reading text for each individual and for the group as a whole.

RESULTS

All of the subjects passed the quiz on the comprehension of the text. The mean score was 81% correct. Based upon the criterion of a 60% passing rate we accepted the measurements of the eye movements as valid. There was less success with the results of the musical quiz. Two of the nine subjects correctly identified three of the melodies that were written into the music, but the mean score was correct identification of only 1.55 of the four melodies. One of the factors that may have caused this low mean score was that the musicians were only given one reading of the musical text. A second and important factor was that the music was written so that it had no measure bars, no tempo or key signature information, and no change in length of the notes. By composing it in this way we eliminated all of the clues that musicians typically use to identify melodies. It is reasonable to assume that the low scores in the musical quizzes were the result of this flaw in the quiz design. The major purpose of the melodies was to provide a cognitive demand for the musicians to attend to the music (similar to that of the text card), and this purpose was achieved by asking the musicians to listen for them. The eye movements obtained while the subjects read music were still very usable.

In all but one of the subjects there was a large difference between the mean number of saccades in reading music com-

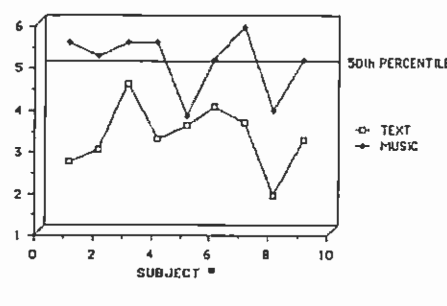

Figure 4.
This graph compares the saccades per second between the tasks of reading music and reading text. The line on the top of the graph represents the 50th percentile of the values for reading music, which is equal to 5.18 saccades per second.

Subject Data				
Subject #	Time To Read Text (Seconds)	Time To Play Music (Seconds)	Saccades Per Second Text	Saccades Per Second Music
1.	16.50	128	2.67	5.50
2.	19.80	91	2.93	5.17
3.	14.70	161	4.49	5.50
4.	15.75	116	3.21	5.50
5.	14.70	122	3.53	3.75
6.	11.37	108	3.95	5.08
7.	18.20	119	3.57	5.83
8.	18.58	100	1.83	3.88
9.	18.40	134	3.15	5.08

Table 1.

Statistical Data	Text	Music
Mean	3.259	5.032
STD Dev	0.764	0.773
Minimum	1.83	3.75
Maximum	4.49	5.83
DF	8.00	
Paired T	6.506	
Probability	.0001	

Table 2. The statistical comparison of the number of saccades per second between reading text and music.

pared to reading text (see Figure 4 and Table 1). The mean number of saccades found when the subjects read the Eye Trac text was 3.26 per second. The corresponding mean number of saccades obtained when the subjects read and played music was 5.03. The smallest difference among the subjects occurred in subject number five, who had a difference of .22. The largest difference occurred in subject number one, who had a difference of 2.33. Most of the subjects averaged differences in saccades from 1.50 to 2.00 saccades per second. The mean difference between reading text and reading music is 1.73 saccades per second.

The use of the one-tailed T test demonstrated a level of significance of .0001. We can therefore conclude that there is a significant statistical difference between the mean saccades per second between the two sets of data. The raw data and the statistical analysis are contained in Tables 1 and 2.

A large difference in reading time between reading text and reading music was also found. Average reading time for the text was 16.4 seconds, while for reading music it was 120 seconds. The statistical difference between these numbers is obvious.

We made no attempt in our study to find a correlation between the age, sex and number of years of experience of the musicians, with the average number of saccades per second in reading text or music. All of our musicians successfully played the musical piece, but no attempt was made to analyze any errors in performance. This would be valuable data and should be included in a follow-up study.

DISCUSSION/CONCLUSIONS

By counting the number of saccades we have shown that the eye movements of musicians can be recorded and quantitatively measured, using the Eye Trac. Our data clearly shows that the number of eye movements (saccades) that a musician makes are significantly greater when reading music compared to reading text. It is logical to assume that the accuracy of the eye movements, and the visual demands entailed, must also be greater.

The musical text in our study was written with only quarter notes, but actual music includes variations in the note length and other symbols (for dynamics changes, tempo changes, etc.) that the musician must accurately perceive. Real musical text requires a much greater demand for visual accuracy than the task in our study. Lang[8] stated, "The perception of musical scores depends upon a steady flow of exact information obtained visually from the printed music.... The visual axis has to be within a degree or two of such stimuli for very exact information about them to be available to the musician." Because of the exacting visual demands of reading music, any problems in oculomotor efficiency, accommodative flexibility, or binocular stability, can interfere with a musician's sight reading ability. Various optometric interventions that eliminate ocular problems, or improve the oculomotor efficiency of a musician, have the potential to make these individuals better sight readers and better readers of music in general.

Why does reading music require more eye movements? One possible explanation is that in reading text, we combine bits of information (letters) that were seen not as discrete symbols, but as a whole (a word). A number of studies have found that such combinations do not exist in reading music.[9,11] Lang, Schmidt and Weaver[8,9,11] all concluded that when reading, music a note is an equivalent unit to a word (in reading text) during a fixation. In order to correctly play the piece, it is imperative that the musician pay attention to where each note lies within the staff. The greater amount of visual attention given to each note results in a greater number of fixations and corresponding eye movements. Lang stated that "One finds that the musician reads one or two notes which are played, and this sequence continues until the particular score has been completed."[8]

In this study, subjects spent a significantly longer time reading the passage of music (averaging 120 seconds) versus reading the text (averaging 16.4 seconds). This agrees with the observations of Lang,[8] who found that his subjects read text 33% faster than they read music. A possible explanation for this is that reading musical text is indelibly connected to the act of playing music. Sloboda[4] states that in his experience there is no such thing as a person who can truly read music cognitively. The meter, tempo, and even major themes may be recognized by an accomplished reader, but to read the music it must be played. Time must be spent during the fixation to cognitively analyze the music. Time must also be spent to signal muscles to depress the appropriate key. The motoric aspects of playing add to the time of each fixation and this may explain why studies have shown that the durations of fixations are greater when reading music versus text.[11,12,13] A greater duration of fixations, combined with a greater number of eye movements (fixations), results in the greater length of reading times that were observed in this and previous studies.

Despite the fact that the first study on the eye movements of musicians was performed over 70 years ago, the research in this area is still in its infancy. Studies should be performed to test the conclusions of this and previous studies. Additional studies should be directed toward: analyzing eye movements of musicians while reading real passages of music, determining the specific notes where fixations occur, comparing musicians and non- musicians to see if they differ in oculomotor efficiency while reading text, studying the effects of note size upon the number of eye movements (this information could have direct application in changing the print size of music to maximize reading efficiency), evaluating the vertical eye movements, looking into the effect of practice and music complexity on the number of eye movements, and determining the appropriate age that young musicians should be taught to read music. This latter point is particularly important because if reading music is as visually demanding as the literature suggests, it might be more appropriate to teach first by ear, and later train notation reading as the eye movements of the child mature.

Music is truly the universal language, but it is becoming evident that the visual and perceptual processes involved in its production are more intricate than what was once thought. Weaver best summarized this process by stating, "The necessity of producing an exact tonal embodiment of the printed symbols demands a perceptual process which seems to approach the highest degree of complexity, speed and precision possible in human skills."[9] His statement could also add that the process of reading music demands a visual process which also seems to approach the highest degree of complexity, speed and precision possible in all human skills.

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