KEEP YOUR EYE ON THE (VIOLIN) BOW: A STUDY DETERMINING CERTAIN ASPECTS OF SIGHT-READING SKILLS IN VIOLINISTS

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ABSTRACT

The notion of sight-reading, which is performing a music piece without any rehearsal beforehand, is considered to be an essential skill among violinists. With recent advancement in technology comes the rise of eye-tracking studies. This experiment attempted to test if certain musical features such as note density and pitch gaps affect sight-reading speed and performance correctness of violinists through the use of eye tracking technology. Results show that note density and pitch gaps contributed to affecting sight-reading speed, especially with bars with 5 or more notes or with notes which have a pitch gap of 5. Aside from this, there were other consistencies such as three of the four violinists playing closer to sequence than the last one. While these insights are substantial, sight-reading a composition is complex and takes in a multitude of external factors, more than just musical features alone.

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CHAPTER I

INTRODUCTION

One of the most common skill that both novice and veteran musicians practice and strive to master is the ability to sight-read. In the context of music, sight-reading, by definition, is the act of performing a music piece, typically written in music notation, without previous preparation. Despite the name being “sight”-reading, according to the study in sight-reading conducted by Andreas Lehmann and Victoria McArthur, sight-reading is not solely dependent on the musician’s visual acuity; rather, it also involves perception by quickly decrypting note patterns, kinesthetic by training muscle memory, memory through recognizing of patterns, and problem solving skills through improvising and guessing [1]. Since these are the factors that mostly influence the learning of sight-reading, this ability is highly obtainable through training and practice. Practicing this skill is highly encouraged even to novice musicians due to some auditions having tests regarding one’s ability to sight-read. However, this skill may prove difficult to learn, especially to master, even for proficient musicians, which typically requires rigorous training, and a great deal of time and effort.

In testing one’s ability to sight-read, the difficulty of the music sheet given, and the accuracy of the musician’s performance are checked. In several studies analyzing skilled and less-skilled sight-readers’ performance in tests, such as the study by Thomas Goolsby in eye movements during sight-reading, it was seen that there is a clear distinction in the eye movement of skilled sight-readers compared to less-skilled ones where the eye movement, more specifically, the saccades are more frequent and the fixations are shorter for skilled sight-readers while less-skilled ones tend to have longer fixations and less frequent saccades [2]. Based on this, a musician's eye movement during sight-reading may be a possible indicator of his or her sight-reading skills.

1.1 Context of the Study

It is common for music teachers to say that when reading sheet music, one should read not only the bar one is playing but also the bars ahead. With that said, the experimenters want to know if people or musicians can actually do this. In fact, what these music teacher say gives rise to the concept of "eye-hand span" (EHS), which has been tried and tested by past experimenters and psychologists like Dr. John Sloboda, [3]. Eye hand span is defined as the "distance" of hand and eye in terms of sight-reading (i.e., how far is the note being seen by the eye to the one currently being played.)

The experimenters shall also define the following concepts for this thesis:

- Sight-reading speed: the speed, in terms of notes per second, at which the person sight-reads
- Note density: The number of notes per bar of sheet music.
- Pitch gap: the difference between pitches of two notes (such as C and G)

1.2 Research Objectives

This study has achieved the following objectives:

- To use eye-tracking to determine sight-reading speed of musicians
- To determine which musical elements or structures impede sight-reading and performance speed
- To compare sight-reading speed with actual performance correctness and musical expertise

1.3 Research Questions

- Does fast sight-reading speed correlate to musical virtuosity in violinists?
    - How fast can a trained violinist sight-read and what musical elements/features tend to limit their speed?
    - Does faster sight-reading enable or assist one to play a previously unstudied piece of music better?
    - Over a group of subjects, what consistencies can be found amongst their sight-reading speeds and performance correctness?

1.4 Scope and Limitations

The sample size of this experiment will be limited to four violinists from the Ateneo community. The technology the experimenters use will only be limited to the following: microphone and/or camera, Gazepoint GP3 eye-tracker, and computer with Gazepoint Software.

1.5 Significance of Study

This study will show the experimenters' helpful insights into the field of music education and its development as well as the expansion of eye-tracking in other disciplines such as music and cognitive psychology.

CHAPTER II

REVIEW OF RELATED LITERATURE

Sight-reading is a required skill musicians must learn to master. However, while practice improves speed and performance skill, the musician must also know which musical elements that impede their SR speed should they work on. The experimenters will have to delve into the research and previously conducted studies to look for insights to use in looking for sight-reading speed, performance skill, and musical elements which limit these.

2.1 Sight-reading Technicalities

As explained by Andreas Lehmann and Reinhard Kopiez, sight-reading provides complex problem-solving situations with interplay of bottom-up mechanisms and top-down processes. Moreover, they had discussed that the limitations on general playing of instrument or lack of technical proficiency affects the ability to sight-read where one can never sight-read beyond the level of rehearsed performance, and that sight-reading requires training. Lastly, they explained that hours of experience give sight-readers the ability to develop cognitive adaptations, which can help them with impromptu score construction and other tasks. [4]

In an article about sight-reading written by Andreas Lehmann and Victoria McArthur, they aimed to answer the questions: why some people are good sight-readers and others not, how the ability to sight-read is acquired, and how to improve sight-reading performance. In order to answer these questions, they first looked into the nature of sight-reading or reading in general. They discussed that our vision is not of a coherent sharp picture for the whole field of vision like that of a clear photo taken by a camera; rather it consists of the fovea, which is a small area where objects are in focus, and around it, the parafovea, which is the blurrier circle of peripheral vision. Other research they found suggested that some information in the parafoveal area could be processed in addition to those found in the focal area. They further discussed that our eye performs large and small movements at a rate of four to six per second called ocular saccades in order to view images. [5]

2.2 Sight-reading Experiments Focusing on Musician Skills

2.2.1 Without Eye Tracking

In the article "Classification of high and low achievers in a music sight-reading task" by Kopiez, Weihs, and Ligges, they aimed to study a theory on sight-reading which considers relevant factors such as practice-related variables, information processing speed, and psychomotor speed. In their claim, they said that there is no comprehensive model that can classify subjects into high and low performance group. Their study used data mining instead of regression analysis. The data they gathered is based on 52 music students, where they analyzed their total sight-reading performance by the use of an accompanying task [6]. Their subjects were also asked to complete a set of psychological tests that were found to be useful predictors of sight-reading achievement, which involves test of mental speed, reaction time, working memory, inner hearing, and more. They also used classification methods in order to determine combinations of variables for classification. The results they gathered using linear discriminant analysis revealed a two-class solution for four predictors having a cross-validated error of 15%, and a three-class solution with five predictors having a cross-validated error of 33% [6].

In the article written by W. Burt Thompson regarding sight-reading skill in flute players, Thompson investigated factors related to music sight-reading wherein thirty flautists were asked to perform the following tasks: (1) sight-read standard music, (2) sight-read random music, (3) recall music notation, (4) recall letters, (5) eye-performance span, and (6) choice reaction time of playing individual notes. In Thompson's findings, he found a significant correlation between sight-reading and eye-performance span and music recall, but did not find correlation between sight-reading and letter recall, which reflects similar results to previous studies in sight-reading with pianists. Thompson also found significant partial correlation regarding sight-reading skill and eye-performance span when music-reading ability was controlled. Thompson's results are consistent with the idea that increased skill involves both speed up of individual processing stages and the degree of parallel operation of said stages [7].

In the study conducted by Michele Henry on the effect of pitch and rhythm difficulty regarding the performance on vocal sight-reading, Henry determined the relationship between pitch and rhythm tasks occurring concurrently. Henry's study used 253 high school singers, who were asked to sing melodies with varying combinations of pitch and rhythm difficulty. Results gathered by the author showed that rhythm and pitch successes are related to each other, where rhythm accuracy without pitch success was least frequent while pitch accuracy without rhythm success was most frequent. Results also show that singers tend to give priority to pitch over rhythm, and that singers with instrument experience scored significantly higher than those without instrument or piano training [8].

2.2.2 With Eyetracking

In the early 2000's, Reinhard Kopiez and Niels Galley performed a pilot study to compare eye movement in musicians versus those of non-musicians. For this experiment, they assumed two things: (1) early exposure to and practice in playing musical instruments can affect the way a professional musician processes visual information, and (2) eye movements of a person determine some kind of "fingerprint", a way in which they process what they see about them. [9]

Pitting a group of 8 professional musicians against 254 psychology students (also known as the control group), Kopiez and Galley asked each of them to perform an oculomotoric or "eye movement" task: to follow a dot or "jumping point" moving horizontally across the computer screen in a waveform motion. An electrooculogram was attached to them in order to measure electric potential changes around their eyes while a headrest kept each subject in place. The subject was also asked to perform a series of tasks along with following the dot such as connecting numbers or tapping on a Morse key for 30 seconds. [9]

After the experiment, Kopiez and Galley took all response rapid eye movements or ***saccades*** of subjects as they followed and grouped them into the following [9]:

- **Misses** - response saccades whose amplitude is less than forty percent of the target amplitude, or response saccades that did not fall into the critical time frame (-300 to +300 milliseconds) when the trigger signal occurred, that is, the dot appeared.
- **Anticipatory saccades** - response saccades that fall within -300 to +90 ms of the trigger signal
- **Reactive saccades** - response saccades that fall within 150 to 300 ms of the trigger signal.

Based on their data, Kopiez and Galley found that the ‘musician’s glance’ had few misses, shorter reactive saccades and many anticipatory saccades. They also saw that professional musicians performed highly and had efficient strategies in “following the dot”. However, they comment that whether superior skills of musicians are brought about by early exposure or some other effect is not fully answered, and that their experiment could be open for future research. [9]

Due to the concept that expert musicians are able to hear what they are reading, the researchers Drai-Zerbib, Baccino, and Bigand suggested that expert musicians are then able to process and integrate multi-modal information. In order to determine if this is true, they used an eye-tracking technique on two groups of musicians, experts and non-experts, and made them read excerpts of little-known classical music and then play them in a keyboard. They then run the experiment in two consecutive phases: (1) simple reading of music piece where there is no playing of piece involved, and (2) sight-reading. In the results of the experiment, they found that in half the conditions, participants heard music before engaging into reading. Moreover, their hypothesis of model independence of information among expert musicians compared to non-experts is validated through the analyses of first-pass fixation duration, second-pass fixation duration, probability of re-fixation, and playing mistakes. The results they gathered are then discussed in terms of processing cues and retrieval structures as postulated by Ericsson and Kintsch in their model of expert memory. [10]

2.3 Sight-reading Experiment/s Focusing on Musical Elements

2.3.1. Without Eye-Tracking

In 1974, Dr. John Sloboda experimented on the concept of "eye-hand span", which he defined as "the amount of material, measured in number of notes, that can be correctly played following the note on which the text was made invisible," and saw how it relates to "eye-voice span" of English reading.[3]

In his experiment, he asked 10 different subjects, all of them with background in music, to play 15 different melodies. These melodies were written carefully so that notes were evenly spaced out from each other and then shown to the test subject via photographic slides. While the test subject was playing the piece, Sloboda would turn off the projector at two different points: early in the piece of music the subject was playing and late into the piece of music the subject was playing. He would then count how many notes the subject was able to play until he or she could not remember anymore and record them. [3]

Important variables that he recorded were the number of errors the subject made prior to the cut-off, and the number of notes the subject played up to the end of a phrase boundary.

What Sloboda discovered from the experiment was (1) by using the number of errors to measure subject's ability, E.H.S and ability were closely related just as E.V.S. and ability were, (2) by using the phrase boundary as a "standpoint", the number of subjects who finished up to the phrase boundary varies inversely with the distance (in notes) of the phrase boundary to the cut-off point --- quite similar a result to having a shorter EVS with longer text---, and (3) by comparing with Levin's experiment on phrase units having an effect on E.V.S., a phrase boundary significantly affected the

E.H.S of a subject; the better the E.H.S. of a musician, the more often he or she would reach a phrase boundary. [3]

While he acknowledges that EHS and EVS have similar properties, he also acknowledges that they do have some differences. For example, it is difficult to apply the notion of chunking and parallel processing to sight-reading because the music would have to be processed in the subjects' minds before being divided into chunks [3]. This implies that subjects would have known what they were playing before they were playing said sheet music.

In the research made by Thomas Goolsby on eye movements during sight-reading, he measured the temporal and sequential component of the eye movement of both skilled and less skilled sight-readers where they were tasked to sight-read three melodies of varying level of visual detail concentration. The order, duration and location of fixation were checked while the musicians sight-read the music pieces. As he had seen from the results, the musicians do not fixate on note stems or the bar lines that connect eighth notes. He had also indicated the difference of the results of the less skilled sight-readers compared to the more skilled ones where less skilled sight-readers progressed through the melody note-by-note, and with long fixations while the skilled ones progressed through the melody with fixations to all areas of the notation, and with more eye regression. The skilled sight-readers also had larger perceptual span, and they look farther ahead in the notation then return to the point of the performance during sight-reading. From the results, Goolsby concluded that music reading is music perception, supporting Sloboda's claim [2].

In an experiment conducted by Frances Truitt, Charles Clifton, Alexander Pollatsek, and Keith Rayner on perceptual span and eye-hand span in sight-reading, they measured the perceptual span, defined as the range of sight with sharp enough visibility in order to accurately perform an action, of pianists by using the moving-window technique while playing single-line melodies with four beats per measure. The results show that the performance of the pianists on the four-beat, six-beat, and no window conditions were generally similar. However, in the two-beat window condition, the playing time were longest, fixations were longer and more frequent, and saccades length were shorter when compared to the four-beat, six-beat, and no window condition. From the data they have gathered, they concluded that the perceptual span for pianists was at least one whole measure in order to perform the piece normally. As for the eye-hand span, which they determined by comparing the eye movement data and keypress data of the pianists, they had seen that the two-beat window condition yielded the smallest eye-hand span while the no window condition yielded the largest eye-hand span. Lastly, they had also examined the effect of skill on the playing time, fixation, and saccades length, by comparing the results of the more skilled pianists and the less skilled ones. They had seen that skilled sight-readers had less playing time, shorter fixations, and larger eye-hand spans compared to the less skilled sight-readers [11].

In the work of the researchers Veronica Kinsler and R.H.S. Carpenter regarding the saccadic eye-movement on music reading, they measured the subject's eye movements while reading music consisting of only rhythmic information written in conventional music notation. Their findings suggest that the relationship between the displayed spatial pattern and the fixations made when reading those patterns is stochastic. Their results also show similar findings to that of reading ordinary texts, but with more tendency to focus more on salient details such as the bars and notes rather than the spaces in between. Additionally, they found that shorter notes are less likely to get fixated due to their performance length rather than their visual appearance. In spite of the timing constraint in music reading, their findings suggest that the time of execution of individual saccades and the time of execution of elements of the performance itself is unrelated. However, they found that the increase of tempo in performance lead to the decrease of the average time between saccades with the increase of their mean amplitude. Through their observations, they found that a new model of oculomotor and perceptual process are involved, in which the central iconic representation of image is scanned and interpreted to a given criterion of accuracy where if the criterion is not reached, the scan ends at that point, and this end-point is then used to determine the next position of fixation. Furthermore, they proposed that fullness of buffer between perceptual and motor processes determines the strictness of criterion adopted, hence the amplitude and eye timing of movements [12].

2.3.2 With Eye-tracking

So far only one eye-tracking study exists that focused specifically on violinists. Wurtz, Mueri, and Wiesendanger (2009) found that their results suggested that structural differences in the score, namely its complexity, reflected in the eye-hand span of their subjects: the more complex a score, the longer the fixation durations and the more regressive fixations. [13] However, the study also found that depending on the structure of the piece, the subjects would adjust their playing tempo during sight-reading: one of the two scores featured more 16th notes, which the subjects interpreted to be played faster. They also only estimated one score to be more complex than the other due to its (1) less regular notation pattern and (2) higher complexity of intermittent position changes and fast triple sequences [13].

2.4 Measuring Statistical Significance of Music Features

In a study by Sébastien, Sébastien, and Conruyt (2011) on the development of a collaborative web platform that could automatically and dynamically create music lessons, they proposed seven difficulty criteria that affected the level of a piano piece. These criteria could be estimated as scores by the platform from a MusicXML file, and averaging these scores resulted in an approximate difficulty level for the piece. [14] Modifying and adding upon these criteria, Chiu and Chen proposed in a 2012 study a regression-based classifier that identified certain symbolic music features and scored them according to certain formulas to assess the difficulty of piano sheet music. During the study they came up with eight features/criteria that wholly characterized a piano piece [15], the table of which is shown on the next page.

Table 2.1*. Difficulty features for classifying piano music according to Chiu and Chen* (2012)

Difficulty feature	Description
Playing speed (PS)	Tempo: speed or pace of a musical piece. It is indicated by a word (e.g. Andante grazioso) or a value in BPM (Beats Per Minute)
Pitch entropy (PE)	There are 128 distinct pitch values in MIDI. Generally speaking, the pitch range of piano is from A0 (27.5Hz) to C8 (4186Hz). The pitch entropy measure the information content of pitch value.
Distinct stroke rate (DSR)	Stroke: it is a stroke while a note or a rest occurs. Consider all distinct strokes between left and right hands.
Hand displacement rate (HDR)	A hand displacement measure difficult while the interval between two successive notes (or two chords) is larger than some semitones (or between two farthest notes). The displacement cost (DC) of an interval increases according to it gap length.
Hand stretch (HS)	Hand stretch is measured by computing difference between left and right average pitch value.
Fingering complexity (FCX)	Fingering: Arrangement of finger and hand position on the keyboard, For example, 1=thumb, 2=index finger, 3=middle finger, etc.
Polyphony rate (PPR)	Polyphony: notes sounded simultaneously
Altered note rate (ANR)	Different tonalities impose different sharps and flats as key. C major and A minor are the most basic one without alteration.

CHAPTER III

METHODOLOGY

3.1 Experiment Proper

For this experiment, the experimenters will use stratified sampling among the students from UP College of Music to obtain ten representatives of the experiment divided into two subgroups classified by their skill level in playing the violin: 5 samples of advanced violin players and 5 samples of novice violin players. The samples will be obtained through coordinating with a professor of the UP College of Music by sending him or her a formal request letter. The request also includes that, if possible, the professor selects the samples of students according to the classification specified. After which, the experimenters will coordinate with each representative to fix a schedule to which they can conduct the experiment with adviser/s and representative. They will be asked to use their own preferred violins to ensure no discomfort that could possibly affect their performance.

The setup of the experiment looked like this:

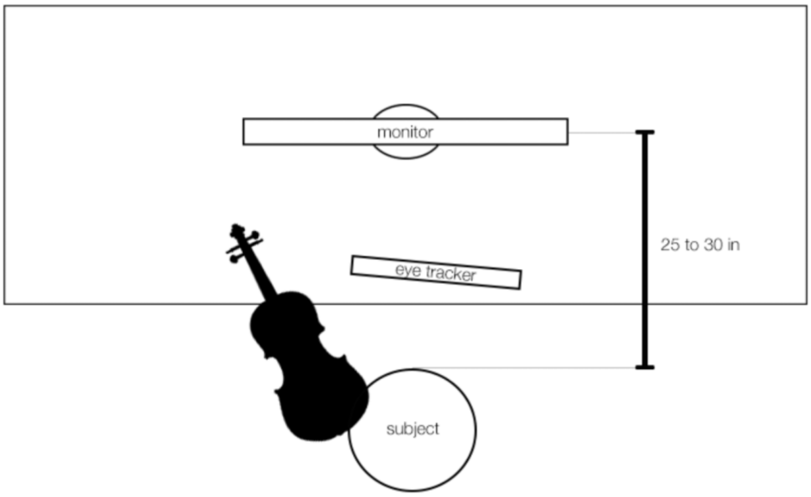


Figure 3.1. *Setup of experiment.*

Before the experiment, the setup will be the following: (1) A computer will be set up a few feet from the participant and the experimenters. (2) The eye-tracking device that will be used, GazePoint, will be set up a few inches away from the computer. (3) A microphone that will capture audio will be set a few inches from the computer. (4) The Participant will be set 1-1.5 feet away from the computer screen. (5) Experimenters will open the GazePoint software before the experiment starts.

During the experiment, the flow will be move to the following sequence: (1) Experimenters will perform 5-point / 9-point calibration test with participant. (2) The microphone will be set to start recording audio. (3) A sheet music will be displayed on the computer where the participant will then be asked to play the respective piece. These sheet music will be developed and selected so as to contain various music features that help objectively differentiate them from one another in terms of difficulty. (4) The experimenters will check the heatmap generated by GazePoint to ensure that there are little to no jitters in the data captured.

3.2 Creating the Pieces

Prior to the experiment, the experimenters have decided to use note density and pitch gaps as the features to test on. At the recommendation of the adviser, each experimenter created three different pieces of 12 bars of sheet music: in the following categories:

- Set 1 - constant pitch gap and varying note density
- Set 2 - varying pitch gap and constant note density
- Set 3 - varying pitch gap and varying note density

Over time, these pieces have been revised, edited, and validated by the adviser, an external validator, and a feature extractor called jSymbolic.

3.3 Post-Experiment Data Analysis

After the experiment, the experimenters will sync the eye-tracking video data with the audio data in order to measure sight-reading speed. Afterwards, they will analyze all the data and categorize each subject based on their skill in playing the violin, accuracy of performance, and their music reading speed.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Trial Experiment

To test the experiment, the experimenters did a trial run with two members from the Ateneo Blue Symphony. Both experiments yielded different results.

4.1.1 Eye-tracking Results and Comparison

Person 1 had a more broad range of vision, but most of the saccades and fixations clustered to the right and bottom of the screen, towards the more clustered notes; this is quite evident in Set 3. Meanwhile, Person 2 had a more center based-focus but tried his best to reach all the notes, despite not finishing to play the whole sheet music of Set 1.

4.1.2 Audio Results and Comparison

Person 1, having had more experience, played quite well, hitting all the notes correctly and transitioned from one note to the next smoothly. Person 2, meanwhile, had a bit of trouble in playing Set 1, given that transitions took a little longer than expected.

4.2 Experiment Proper

4.2.1 Sheet Music Statistics

The sheet music was designed varying two particular musical features: note density (number of notes per unit time), and average pitch gap (known in jSymbolic as mean melodic interval, the average difference between consecutive notes in semitones). Three sets of three sheets were created, based on the criteria previously mentioned, with the following statistical values extracted using jSymbolic:

***Table 4.1**: Sheet Music Statistics*

Sheet	Pitch Gap (semitones)	Note Density (notes per second)
1-1.mid	4.449	1.736
1-2.mid	4.475	2.128
1-3.mid	4.42	2.431
2-1.mid	4.306	1.736
2-2.mid	4.98	1.736
2-3.mid	5.531	1.736
3-1.mid	4.49	1.736
3-2.mid	4.983	2.048
3-3.mid	5.448	2.361

The sheets were also designed such that Set 3, the set of sheets that would vary both features, would vary these features almost similar to Sets 1 and 2 in order to ensure statistical correctness, as shown in Figure 4.1.

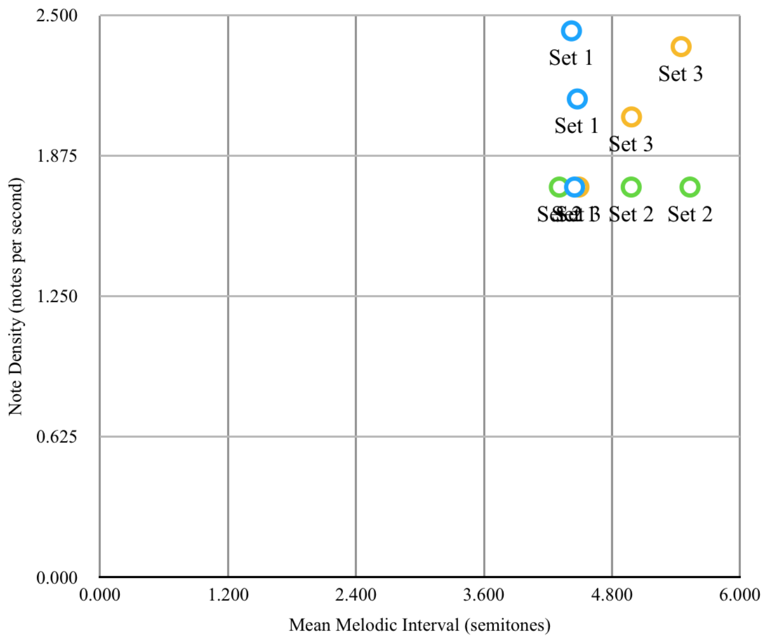


***Figure 4.1.** Mean Melodic Interval vs. Note Density scatterplot of Sets 1-3.*

4.2.2 Volunteer Backgrounds.

The experiment has been conducted on four violinists with varying number of years playing the violin and varying scale of familiarity with the G Major. Here, the experimenters can see two distinct pairs of participants. The first pair, composed of Persons 1 and 2, had less than five years playing the violin but were most familiar with the G major scale, be it tenor clef or alto clef[1]. Both of them answered 10 on the familiarity scale. The second pair, composed of Persons 3 and 4, had more than 5 years of experience with the violin but were not as familiar with the G major scale as the first pair. They answered 8 and 7, respectively on the familiarity scale.

4.3. Results and Analysis of Eye-tracking Experiment.

4.3.1 Preliminary Data

Overall, the four volunteers of the experiment, given their backgrounds, showed some correspondence between sight-reading speed and performance quality in their performances. Persons 1, 3, and 4 had similar results. Person 2, meanwhile, was an outlier. In order to provide some background, shown on the next page is a table tallying the performance time of each person per piece.

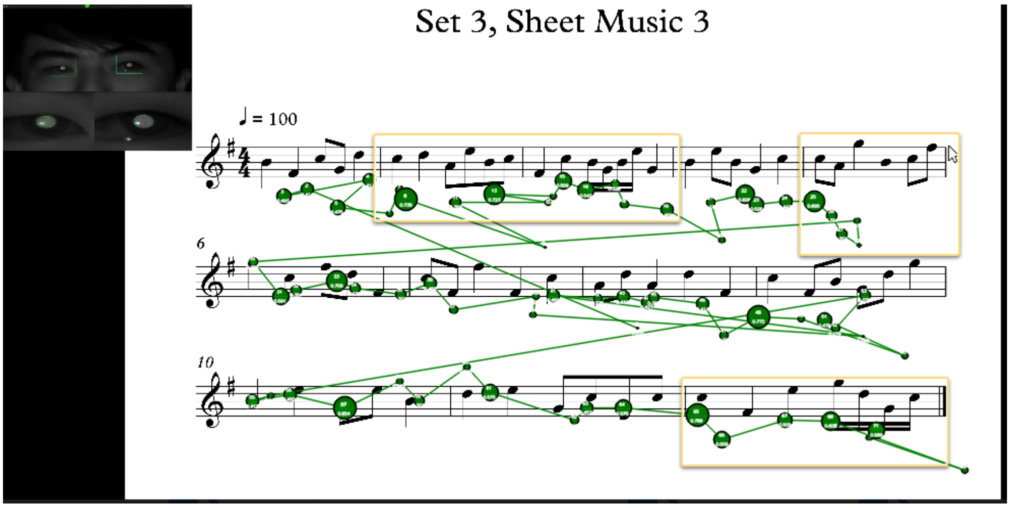
[1] Person 2 was more familiar with the alto clef, and so the experimenters asked him to play the major in that clef.

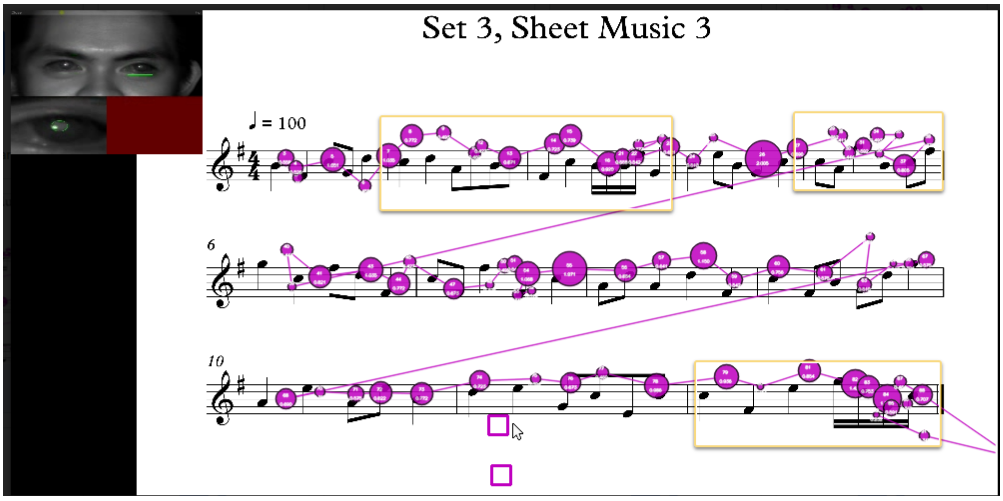
Table 4.2 *Table showing the performance times (in seconds, rounded to two decimal places) of each score by the four volunteers*

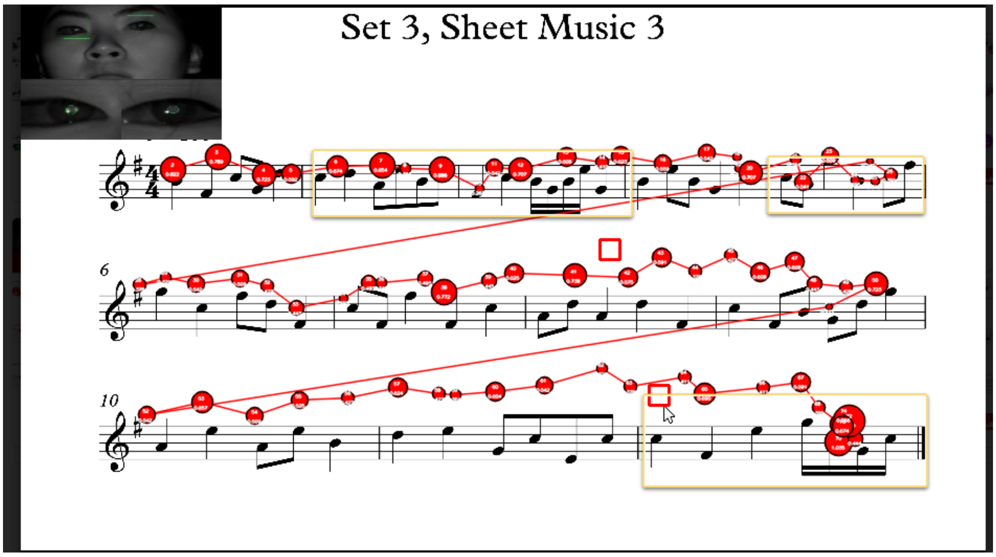
Person	Set 1				Set 2				Set 3			
	1	**2**	**3**	**Ave.**	**1**	**2**	**3**	**Ave.**	**1**	**2**	**3**	**Ave.**
1	39.07	41.88	35.81	38.92	36.47	35.21	34.60	35.43	33.76	34.13	32.13	33.34
2	48.86	70.68	70.59	63.38	43.06	50.37	51.60	48.34	44.67	53.21	57.93	51.94
3	32.08	30.62	32.33	31.68	33.28	33.61	33.63	33.51	40.74	38.36	40.71	39.94
4	35.24	36.34	39.56	37.05	35.49	38.57	37.88	37.31	35.29	36.09	40.79	37.39

After looking at all the fixation diagrams of all volunteers, the experimenters discovered primarily that fixations clustered heavily around the bars with eighth-notes or sixteenth notes, especially those notes which appear as a group of four. These groups of four appeared in only 14 out of 108 bars, but they had the most fixation activity, with a few gaze points ranging as long as 0.7 ± 0.3 seconds. This was consistent for all four violinists throughout the sheets. Aside from this, the experimenters observed major fixation activity around places where pitch gaps with at least 5 semitones appeared. Like the findings of note density, gaze points were, on average, 1 second long. Small gaze points (≤ 0.5 s) appeared in clusters on those areas, sometimes accompanied with larger (≥ 0.5 s) gaze points.

Shown on the next two pages are results of the four volunteers in Set 3, Sheet Music 3, with significant areas of evidence highlighted by the experimenters.


Set 3, Sheet Music 3
♩ = 100
6
10


Set 3, Sheet Music 3
♩ = 100
6
10


Set 3, Sheet Music 3
6
10

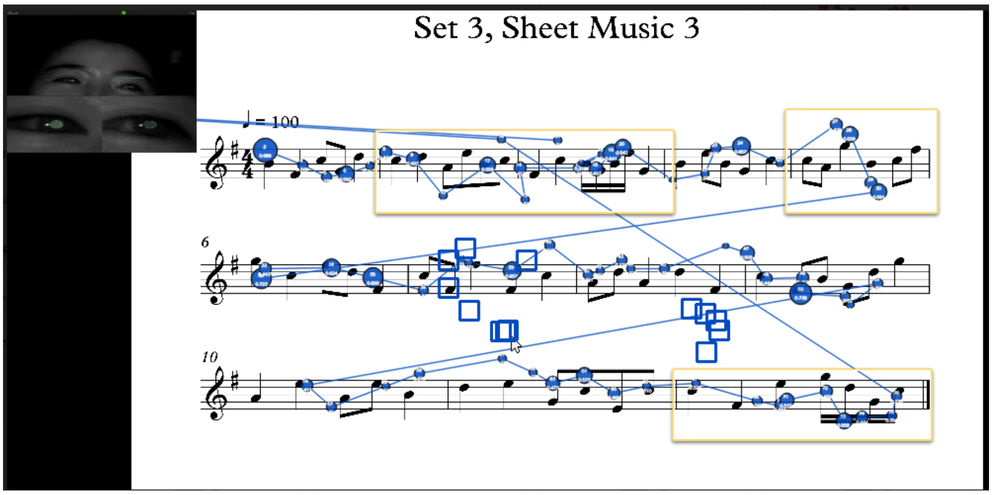


Figure 4.2. *Results of Persons 1 (green), 2 (purple), 3 (red), and 4 (blue) after sight-reading Set 3, Sheet Music 3.*

Aside from these, the experimenters had two other noticeable observations. First of them was that the diagrams of Persons 3 and 4, specifically the horizontals, were smoother and more defined, and they had less fixation points on the horizontals than those of Persons 1 and 2. Second of them was that Person 2, being more familiar with the alto scale than the tenor, had fixations running off the bounds of the image. This is due to his looking at the violin while playing the notes. In fact, his times are considered outliers from the others because he played the notes one at a time unlike the other three, who played the sheet music smoothly. The fixation diagram of Person 2 above the diagram was actually run through an outlier filter for easier analysis. Shown on the next page are the filtered and unfiltered results of Person 2 in Set 3, Sheet Music 3.

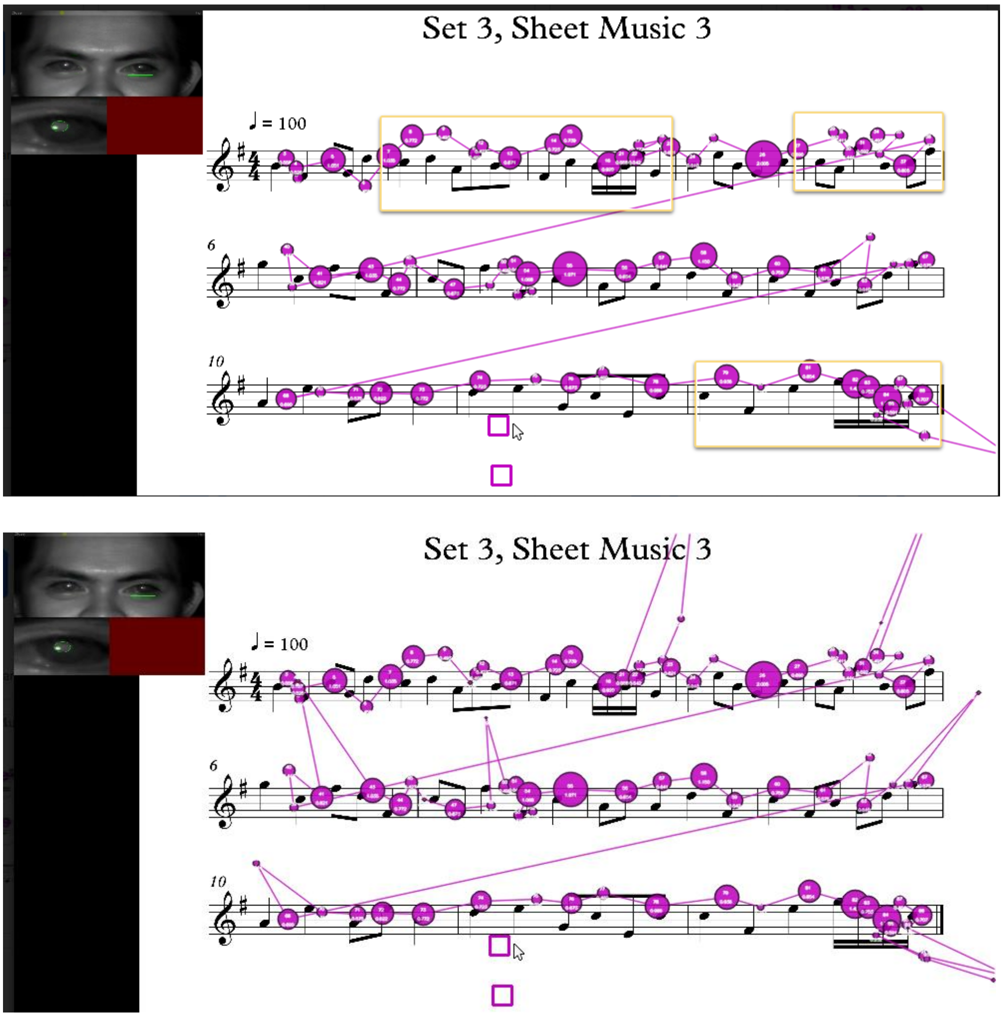


Figure 4.3. *Results of Person 2 after sight-reading Set 3, Sheet Music 3, filtered (top) and unfiltered (bottom)*

4.3.2 AOI Visual Time Analysis

Aside from preliminary visual data, the experimenters went deeper to use AOIs to compare and contrast results. Each AOI covered a bar in each of the scores used in the experiment (12 AOIs per score, 108 total). A major insight found by the experimenters was that for each of the sets, bars with pitch gaps above 5 semitones and note density with 5 or more notes generally exhibited the longest fixation time, save for a few exceptions. To come up with this, the experimenters decided to take the top 3 bars for each person per sheet which had the longest times and then aggregated them.

Table 4.3 *Table showing the bars which were selected as "Top 3" longest viewed bars per person per sheet, aggregated.*

Score	Bars selected
1-1	A, B, D, G, H, J, K, L
1-2	A, B, C, D, F, I, J
1-3	A, C, D, H, J, K, L
2-1	A, B, D, G, J, K, L
2-2	A, B, C, G, H, I, L
2-3	A, C, D, E, G, H, I, K, L
3-1	A, C, E, F, G, I, J, K, L
3-2	A, B, C, E, G, I, J, K
3-3	A, B, C, F, G, I, L

While most bars selected had more than five notes or had a pitch gap of more than five semitones, other bars selected may have had some contribution to being in the aforementioned table. Some of the bars had rests, which may have contributed to lengthening the fixation time of the bar.

Another unexpected appearance on the list is the inclusion of Bars H and J of Sheet 1-1, while H has a rest inside, J was a bar of 4 notes and pitch gap less than 5 semitones. Perhaps the volunteers were supposedly looking at bar I, but had their focus on bars H and J instead, as if they were playing both bars as one.

4.3.3 AOI Sequence Analysis via Levenshtein Distance

The Levenshtein edit distance (LD) is the number of insertions, deletions, and substitutions needed to transform one string to another [16]. The experimenters used this distance to see if the sequence of sight-reading the AOIs have some implications on the skill level of the volunteers, using an online calculator to assist them in performing the job. To denote Levenshtein distance, the experimenters shall use this notation: LD(x, y), where “x” and “y” denote sequences. As an example, LD(2, 3) will be referred to as “the Levenshtein distance between the sequences of Person 2 and Person 3”. Also, LD(x, y) = LD(y, x) as the experimenters have found out.

A first way of analysis shows that that the Levenshtein distances of Person 1 with other volunteers (LD(1, 2), LD(1, 3), LD(1, 4)) had higher edit distances than those of Persons 2, 3, and 4 comparing with each other (LD(2, 3), LD(2, 4), LD(3, 4)), save for Sheet 2 - 1---Person 4 had higher Levenshtein distances when compared with Persons 2 and 3.

Table 4.4 *Table showing the Levenshtein distance of persons against each other.*

Lev. Distance	**Set 1**			**Set 2**			**Set 3**			**Ave.**
	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	
LD (1, 2)	12	10	8	10	8	7	9	10	10	9.33
LD (1, 3)	9	10	10	11	9	8	11	10	10	9.78
LD (1, 4)	11	10	10	10	7	10	11	10	10	9.89
LD (2, 3)	5	9	7	4	7	7	2	0	0	4.56
LD (2, 4)	6	6	8	12	5	8	6	0	0	5.67
LD (3, 4)	10	5	7	12	7	5	7	0	0	5.89

Another way of analysis is done by comparing the Levenshtein distance of each AOI sequence of each Person with the normal sequence, which the experimenters shall define as N = {A, B, C, D, E, F, G, H, I, J, K, L}. In order to make sense of this finding, the experimenters shall arrange the Levenshtein distances into a scale, marking 0 as sequential, 12 as nonconsecutive, and 6 the midway point.

Table 4.5 *Table showing the Levenshtein distance of each person to the normal sequence N.*

LD	**Set 1**			**Set 2**			**Set 3**			**Ave.**
	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	
LD(1, N)	12	10	10	11	8	10	11	10	11	10.33
LD(2, N)	5	9	7	8	3	4	3	0	0	4.33
LD(3, N)	8	0	0	8	4	7	2	0	0	3.22
LD(4, N)	11	5	7	10	6	5	6	0	0	5.56

In both ways, Person 1 generally had the highest Levenshtein distances. These distances may have come about because his gaze tended to look towards the bottom of the stave and into the white space between the staves, which caused Gazepoint to register his gaze into the lower, and therefore, later AOIs.

Meanwhile, Person 2 had lower distances when compared against Persons 3 and 4 and sequence N. This was brought about by his slower sight-reading and performance times and his unfamiliarity with the violin.

Meanwhile, Persons 3 and 4, both with the most musical experience. had generally lower scores against N, which implies that they followed the bars sequentially while reading. This finding actually contradicts the results of Goolsby's study [2] that more experienced musicians would have greater saccades (and hence higher Levenshtein distances). However, this comparison of higher and lower Levenshtein distances is dependent on Person 1's results, whose high scores are contestable, which means the contradiction could possibly not exist.

4.3.4 Visual and Auditory Comparison

The audio recordings of the performances were analyzed in order to gain more insight on their sight-reading and its effect on their actual playing. The following table contains the performance times per person per sheet based on these recordings.

Table 4.6 *Table showing the performance times (in seconds, rounded to two decimal places) of each score by the four volunteers, based on the audio recordings.*

Person	Set 1			Set 2			Set 3		
	1	2	3	1	2	3	1	2	3
1	35.76	36.65	34.08	32.78	31.59	30.10	30.15	30.03	30.79
2	42.03	50.57	49.37	38.09	46.75	47.22	40.70	50.24	52.88
3	28.43	26.80	30.02	30.18	29.56	29.74	36.50	34.61	36.69
4	31.42	33.68	33.60	32.05	34.69	32.98	31.20	32.94	33.93

These performance times are all shorter than the recorded performance times based on the visual data. This likely due to the non-simultaneous start of recording their eyesight and the actual start of their performance, as well as the lag time while switching between sheets, which the visual data also records. Despite this, the comparative performance times were consistent with observations from the visual performance times.

The average performance time per set was calculated for both visual and audio performance times:

Table 4.7 *Average performance time per set (in seconds), for visual and audio data*

Data Set	Set 1			Set 2			Set 3		
	1	2	3	1	2	3	1	2	3
Visual	27.78	30.11	29.47	28.97	29.91	28.59	29.27	31.22	32.38
Audio	34.41	36.92	36.77	33.27	35.65	35.01	34.64	36.95	38.57

Set 1 had slightly slower performance times than Set 2, implying that note density affects sight-reading speed more than pitch gaps. Set 3, varying both features, had the slowest performance times, and as the feature values increased the performance times also increased consistently, unlike Sets 1 and 2.

Similar to the visual data analysis, the audio recordings were also analyzed per bar, corresponding to the AOIs of the visual data, in order to see inconsistencies with the playing speed over the duration of each sheet, and possible correlations with the results of the visual data. The top 3 bars that had significant increase or decrease in playing time compared to the previous bar were selected. This deviation was quantified as anything greater than 2 standard deviations from the average playing time per bar.

Table 4.8 *Bars with significant increase or decrease in playing time.*

Person	**Set 1**			**Set 2**			**Set 3**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1	F, I, L	D, E, K	H	B	F	D, F, J	C, F, G	—	K
2	B, D, K	B, C, G, J	C, D, H	A, L	G, I	C, H, I	G	C	C, G, L
3	A, B, H, L	C	D	A, B, H	C, G, I , K	D, F	D, J	D, F	D, G
4	A, B, H	B, D, J	I, K	A, B, H	D, G, L	C	H	E, G	C, L

Comparing these bars to Table 4.3 reveal that the bars with longer fixation times also had longer playing times, but it could also be observed that these bars also affected the playing times of the bars adjacent to them. This aligns with most sight-reading studies that observed how musicians would read ahead [2, 3, 11] leading to the existence of the eye-hand span.

The errors made during the performance were also counted, per bar. Errors the experimenters considered were note pitch and note duration errors, missed notes, bar repeats, pauses between notes and pauses between bars.

Table 4.9 *Performance errors.*

Person	**Set 1**			**Set 2**			**Set 3**			**Total**
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	
1	1	0	2	2	1	0	0	0	3	9
2	4	0	1	3	2	3	6	4	5	28
3	0	1	0	1	3	0	4	4	2	15
4	2	0	1	4	3	2	2	1	4	19

It can be observed that more errors were made in Set 2 than in Set 1, which imply that pitch gaps affect performance correctness more than note density, contrasting the results on performance time. However, increasing the value of the musical features do not necessarily correspond to more mistakes.

Generally the faster sight-readers made the least mistakes per set, but this association could be due to the volunteers' tendency to slow down whenever they made mistakes. Also, while Persons 1, 3 and 4 had similar performance times, Person 1 made significantly less mistakes in Set 3.

4.4. Effects of Musical Features versus External Factors

Mishra [17] distinguished study-level variables from constructs in her meta-analysis of 92 sight-reading studies published from 1925 to 2010. Study-level variables included performer experience and type of sight-reading tests, such as researcher-constructed sheets, WFPS, sight-reading grades, and repertoire (used in [13]), while constructs were more individual-specific, like age, perception, practice, etc. Most sight-reading studies aimed to observe the effects of the constructs on sight-reading, while the experimenters in this study tried to observe the effects of varying musical features, which fall under study-level variables.

Mishra concluded that sight-reading tests had little influence on the sight-reading results, but that this could be due to the insufficient number of studies to cover all the levels of the study-level variables. The same can be observed for this study, wherein despite the observed consistent effects of the variations in musical features, the differences between the volunteers' individual performances would still be generally attributed to their improvisation, ear-training ability, technical ability, and music knowledge [17], which the experimenters did not take note of for the study.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Concluding analyses and insights

5.1.1 On the sight-reading speed of a trained violinist and what musical elements limited their speed

1. "How fast can a trained violinist sight-read?"

The average fixation time of the trained violinists Person 3 and 4 for Set 1, Set 2, and Set 3 are on average in seconds are 34.37, 35.41, and 38.67, respectively. On the other hand, the average fixation time of a novice violinist Person 2 for each of the sets in seconds are 63.38 for Set 1, 48.34 for Set 2, and 51.94 for Set 3.

2. "What musical elements/features tend to limit their speed?"

Pitch gaps had a slightly greater impact on slowing down sight-reading speed compared to note density as evident on the average performance times of all of the volunteers in completing Set 1 which is 36.03 seconds compared to their average performance times in completing Set 2 which is 34.64 seconds. Moreover, combining musical features, in this case, note density and pitch gaps, increases the difficulty of the piece as a whole as seen through having the highest performance times on average of 36.72 seconds.

5.1.2 On whether faster sight-reading skill enables one to play a previously unstudied piece of music better

The three fast sight-readers of the experiment had little errors in performing the nine pieces. Person 1 had the least errors out of all of them with 9 errors across all nine pieces. Person 3 followed with 15 errors across all pieces. Person 4 had the most errors out of all three of them with 19 errors across all pieces. However, while these results are insightful, the speed at which one sight-reads does not imply their correctness.

5.1.3 Consistencies between sight-reading speed and correctness

Three of the four volunteers had average Levenshtein distances from the normal sequence N less than 6. Person 2 had an average of 5.33, Person 3 has shown to have an average Levenshtein distance from the normal of 3.22, and Person 4 has an average Levenshtein distance of 5.56. Person 1, if only offset was applied, would have also had this kind of average as well. These would imply that reading the bars in sequence is still vital, but reading the bars ahead, whether by intent due to reading notes as chunks or by accident, is still unavoidable. Stay close to the sequence, but let the eyes wander a little.

Aside from sequence consistency, there were also consistencies between the sight-reading speeds, performance "correctnesses" of the volunteers. Faster sight-readers tended to slow down when they made mistakes in certain parts of the score. Also, bars with pitch gaps above 5 semitones and with five or more notes proved to be challenging for our volunteers, generally having had the longest fixation times out of all the bars of their sheet music.

5.1.4 ***The Overall Question:*** *Does fast sight-reading skills correlate to musical virtuosity in violinists?*

Faster sight-reading or in other words, lower fixation times, does not always result in better performance or fewer errors in terms of performance correctness or "musical virtuosity". These can be seen in Set 2 where Person 4 having only an average fixation time of 37.31 seconds in playing all of Set 2, yet having 9 mistakes overall, while Person 2 having an average fixation time of 48.34 seconds, but only having 8 errors overall.

5.1.5 Reflective insights

As the insights drawn from the experiment have shown, sight-reading speed affects how they read certain musical features of a composition. Sight-reading a musical piece is affected by a lot of external factors aside from music features, and looking at the sight-reading skill of a violinist needs further experimentation and investigation, and a larger sample size to reduce the effect of external factors into the study. In fact, these insights were drawn from studying a sample size of 4 volunteers, and these insights may change, given a larger sample size. Nevertheless, the experiment has shown to take a major step towards gaining more understanding on the sight-reading of violinists, especially in analyzing study variables like musical features.

5.2 Major recommendations

No experiment is complete with errors, which may lead to unexpected results, some of which are found in Chapter IV. Hence, the experimenters recommend the following:

- **Technology**: A head-mounted eyetracker would be a better fit for the experiment because it can capture eye movements more finely whilst adjusting to the playing position of the violinist, especially when he or she rests his or her head on the violinists.
- **Test Construction**: The experimenters took measures to ensure the variations in the selected musical features among the sheet music were consistent and

significant, but additional work could be done in ensuring other features, such as placements of rests, slurs, staff notes, etc., are controlled to make sure they do not affect the sight-reading data.

- **Unfiltered data**: The experimenters made an error in filtering out way too many outliers, especially from the visual diagram of Person 2.
- **More volunteers from an esteemed music university:** This experiment may be just the beginning of studying the violinist, since the applications of eye-tracking into music are relatively new. More violinists, especially professional ones, would improve this experiment and provide more data for the better.
- **Analysis:** one of the difficulties encountered during analysis was the lack of previous researches that used musical features as a primary variable. The experimenters hope that this study would assist future experimenters who wish to undertake future studies similar to this one.

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APPENDICES

A. Sheet Music used in the Experiment

Sheet Music Set 1: Varying Note Density, Constant Pitch Gaps

Set 1, Sheet Music 1

Set 1, Sheet Music 2

Set 1, Sheet Music 3

Sheet Music Set 2: Constant Note Density, Varying Pitch Gaps

Set 2, Sheet Music 1

Set 2, Sheet Music 2

Set 2, Sheet Music 3

Sheet Music Set 3: Varying Note Density and Pitch Gaps

Set 3, Sheet Music 1

Set 3, Sheet Music 2

Set 3, Sheet Music 3

Thesis Resources: http://bit.ly/ThesisDataRecords