The Influence of Tonality on Sight-Reading Accuracy

by

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Abstract

The present study investigated how knowledge of tonality is used in sight-reading by comparing sight-reading accuracy across three tonal constructs: major, minor and atonal. It was hypothesized that sight-reading performance would be the worst in instances with no tonal information, as participants would be unable to generate appropriate expectancies to guide their sight-reading. To test this, twelve pianists sight-read major, minor and atonal versions of monophonic, homophonic and polyphonic excerpts. The results indicated that pianists performed the major excerpts with greater accuracy than the atonal excerpts. Furthermore, the errors made within the major excerpts were significantly biased towards diatonicism, and there was a global shift towards tonality in participants’ atonal performances, providing a clear demonstration of how pianists’ expectations might have contributed to their sight-reading performance. The diatonic bias was not found in the minor excerpts, suggesting that the minor hierarchy does exert as strong of an influence during sight-reading.
Acknowledgments

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Chapter 1

1 Introduction

1.1 What is Sight-Reading?

Musical performance is the ultimate demonstration of how refined and complex sensorimotor skills can be in humans (Bernstein, 1967). For instance, skilled pianists have been documented to produce up to sixteen notes per second - a succession of movements that is too quick for the visual system to react to - in passages that require a changing order of successive finger movements (Lashley, 1951). Accurate execution of such a task no doubt requires a number of cognitive and motoric processes, and the high consistency in performances across musicians, despite differences in performance style, reflects this (Palmer, 1997). Thus, it comes as no surprise that this area has been, and continues to be, one of the most widely studied areas within music cognition research. According to a survey by Tirovolas and Levitin (2011), the number of music performance studies has been rising steadily over the years, and constitutes approximately 20% of all the studies published in the journal Music Perception since its inception in 1983. These studies have covered a broad range of topics, including the mechanisms of sight-reading and improvisation, ensemble performance, models of motor planning and processing, feedback mechanisms in performance, measurements in performance such as perceptual effects, intonation, vibrato, tempo, timing and dynamics, as well as the physiological, psychological and social factors that influence performance (for a review, see Gabrielsson, 1999, 2003; Palmer, 2013). The present study focuses on the factors influencing sight-reading accuracy.

Sight-reading is defined as the ability to perform a musical score without prior experience with it. It is a critical skill for all musicians, and is often an integral part of learning any musical instrument. As with learning to read text, beginning music readers must painstakingly learn to
match various musical symbols with certain sounds and actions until this process has become automatized (Lehmann & Kopiez, 2009). Interestingly, while most people master reading text at a rather young age, even accomplished musicians can be poor sight-readers. Thus, understanding the underlying processes involved in sight-reading is important for cognitive psychologists and music pedagogues alike.

1.2 Musical Structure, Pattern Recognition and Sight-Reading

Good sight-readers are characterized by their efficiency at rapidly transforming the patterns they read in a musical score into appropriate motor acts (Gabrielsson, 1999; Wolf, 1976). Therefore, a great deal of the sight-reading literature has investigated how expert readers utilize their pattern-recognition skills in order to process musical structures within a score. Bean conducted the earliest of these studies in 1938. He used short tachistoscopic presentations of musical scores to professional, student and amateur pianists, and had them sight-read as much of the score as possible. He found that, on average, the professional musicians were able to sight-read the most correct notes. Bean attributed this result to the fact that the professional musicians relied on pattern recognition. These results were also supported by early eye-tracking studies by Jacobsen (1941). His experiment utilized a device that flashed a light into participants’ eyes and recorded the corneal reflections onto two rolls of moving film: one for vertical eye movements, and one for horizontal eye movements. These two rolls of film were then synchronized (by hand) to assess the number of progressive and regressive saccades, fixation durations, as well as the location of the fixations on the sheet music. The results of the study found that participants could be divided into three groups based on their eye movements: beginner, average, and mature sight-readers. Beginner sight-readers had comparatively more fixations, longer pauses during fixations, and unsystematic patterns of note reading. Average sight-readers had as many fixations
as there were notes, and showed a more systematic approach to reading chords. Mature sight-readers showed the fewer fixations than notes, and showed the most systematic approach to reading chords.

Subsequent studies in sight-reading did not emerge until several decades later. Through a series of studies, Sloboda (1974, 1976a, 1976b, 1977, 1978a, 1978b) conducted a thorough examination of how the structural features of music, internalized through musical training, might influence sight-reading. In particular, he used two measures, the eye-hand span and the perceptual span, to understand the nature of the information that is gathered from a musical score, how this information is stored into working memory, and how the quality and quantity of this information changes as a function of musical experience (Hodges, 1992).

The eye-hand span (EHS) measures the number of notes a musician is able to play correctly once the score he or she has been reading from has been taken away. This measure was derived from the eye-voice span (EVS) used in linguistic research (Levin & Kaplan, 1970), which measures the amount of words that participants are able to recall after the text they are reading is taken away. Certain manipulations can affect the size of the EVS: it is longer for experienced readers (Tinker, 1958) and shorter when the words within the text are unorganized (Lawson, 1961; Morton, 1964). Sloboda (1974, 1977) found comparable results in music using the EHS. He had pianists sight-read melodies that were presented on projected slides, and would turn off the slides at a various distances before the end of a musical phrase (i.e., the place in the music where a natural cadence occurred). The results showed that poorer readers had smaller EHSs, and could only play approximately three or four correct notes after the score was taken away, while skilled readers were able to play up to seven notes, suggesting that the good sight-readers possessed more efficient input coding and storage processes. Furthermore, the EHS was flexible. It had a
significant tendency to extend to phrase boundaries, especially in good sight-readers, allowing
them to identify more notes in longer sequences by grouping the notes into meaningful units and
patterns. In a follow-up study, Sloboda (1977) demonstrated that these EHS extensions occurred
for structural phrase boundaries only - that is, the phrase boundaries that were created due to
cadences in the music, and not visual gaps caused by the half or whole notes usually used to
create cadences.

Perceptual span refers to the visual region from which participants are extracting useful
information. It is measured by providing sight-readers with limited visual access to a musical
score through tachistoscopic displays. Using this technique, Sloboda (1976a) found that
musicians were more accurate than non-musicians in recalling briefly exposed pitch notation
patterns of more than three notes, if the exposure was longer than 150 ms. At exposure times of
less than 100 ms, musicians were no better than non-musicians at identifying specific pitches, but
they were superior at retaining the contour of notational patterns (Sloboda, 1978b). Again, this
difference was attributed to the fact that musicians coded the stimuli based on underlying
structural patterns of the music, whereas the non-musicians had to remember the stimuli as a
purely visual pattern.

1.3 Tonality and Expectations
The sight-reading literature has focused on the pattern-recognition mechanisms in expert readers
that process musical structures within a score. Few studies, however, have manipulated these
structures to measure their effects on sight-reading accuracy. One of the most widely studied
structures in Western music is tonality, which holds organizational rules and regularities on three
distinct hierarchal levels (Tillmann, Bharucha, & Bigand, 2000). The first level consists of 12
musical notes, which are classified as diatonic or non-diatonic depending on which notes they
co-occur with within a specific musical context, or *key*. The second level of the hierarchy consists of chords, which are labeled as major, minor or diminished, and are classified according to their scale degree within a given key. Also, the occurrence of each chord is highly dependent on its position relative to other chords. The third level defines the relationships between different keys, whose strength depends on the number of common notes and chords the keys share. In addition to these three distinct levels, multilevel relations also exist, which define an extensive set of possible relations between musical events within a single musical piece (Tillmann, et al., 2000). When listening to a musical excerpt, the context provided by melodic and harmonic sequences activates the internalized representation of tonality, and is then utilized as a point of reference to help further process incoming musical stimuli. More importantly, it generates various expectations about the music, which, depending on whether these expectations are fulfilled or violated, will elicit different cognitive responses in the listener or performer (Bharucha, 1987, 1994; Carlsen, 1981, 1982; Meyer, 1956; Schmuckler, 1989, 1990, 1997; Schmuckler & Boltz, 1994).

1.4 **Tonality in Sight-Reading**

Tonality is a concept that has been, and continues to be thoroughly researched within music-theoretic and psychological domains of research; however, it is rarely the focus of sight-reading studies. This is surprising, as there is a general consensus among musicians and pedagogues that students must possess a well-developed sense of tonality to read music efficiently (Bean, 1938; Leonard & House, 1959; Heffernen, 1968; Schleuter, 1984). Musicians’ introspective accounts have reported that formal instruction in compositional harmony has often helped them during sight-reading, as they were able to anticipate certain chord progressions (Wolf, 1976). This was later somewhat confirmed by Nuki (1984), who found that the ability to thoroughly grasp
musical structure through extensive training in harmony and compositional elements were factors in memorization, which was positively correlated with sight-reading ability. Furthermore, a study by Grutzmacher (1987) showed significant improvement in the sight-reading abilities of 5th and 6th grade students after 14 weeks of tonal pattern training, which consisted of playing notes, scales and arpeggios through harmonization and vocalization, as well as recognizing major and minor patterns.

Nevertheless, there are currently few studies that have explicitly suggested that one’s knowledge of tonality plays a critical role in sight-reading. Wolf (1976) reports the experience of a distinguished piano pedagogue, Boris Goldovsky, who discovered a misprint in Brahms’ Capriccio, Op. 76, No.2 after a relatively poor student of his played the harmonically implausible printed note during a lesson. The student arrived at a C♯ major chord, and, instead of playing what should have been a G♯ according to formal rules of composition, played the G that was printed on the score (Figure 1). Goldovsky stopped the student, thinking that she had simply misread the music. He quickly realized, however, that he, among countless others, had misread the music simply because he had inferred a G♯ based on the cues given by the musical context. He later devised the “Goldovsky experiment”, which consisted of asking skilled sight-readers to sight-read the Capriccio and find the misprint. He allowed participants to play the piece as many times as they liked and in any way that they liked. However, no musician ever did find the mistake (Wolf, 1976).

To ascertain the generality of this effect, dubbed as the ‘proof-reader’s error’, Sloboda (1978b) replicated the Goldovsky experiment by asking participants to sight-read musical scores that were littered with deliberate misprints. Despite the fact that the participants in the experiment were competent pianists and excellent sight-readers, the level of error on the misprints was as
high as 38%. That is to say, 38% of the time, the participants corrected the misprints to their original note, presumably based on the expectations generated by their knowledge of the tonal hierarchy.

Figure 1. Bar 78 from Brahms’ Capriccio, Op. 76, No. 2. The arrow is pointing to the misprinted note. The G in the chord should be a G♯.

The proof-reader’s error is not the only way in which the influence of tonality on sight-reading performance has been studied. Pitch production errors can be used as a measure instead, as they provide insight into the structural elements of music (such as tonality) that contribute, and sometimes cause conflict, to the planning of a sequence of musical events (Palmer & van de Sande, 1993). A recent study by Fine, Berry, and Rosner (2006) directly measured sight-reading error rate as a function of tonal manipulation. In their study, experienced choral singers sight-sang the part for their own vocal range (either the soprano, alto, tenor or bass line) in four-part Bach chorales. The participants sight-sang four chorales in total, and each chorale differed in the
way it was manipulated. The manipulations were as follows: (1) the participant’s part to be sight-sung remained unchanged, whereas the other three pre-recorded voice parts were manipulated to be more atonal, and thus, less predictable, (2) the participant’s part was manipulated to be more atonal, whereas the other three pre-recorded voice parts remained unchanged, (3) all four parts were manipulated to be atonal, or (4) none of the parts were manipulated. The results showed that the altered versions of the melody led to significantly more sight-singing errors, even when the underlying harmony was undisturbed, and sight-singing melodies with altered harmonies led to significantly more sight-singing errors as well.

1.5 The Present Study

The present study sought to elaborate on Fine, et al.’s (2006) experiment by conducting a similar study with pianists. Pianists’ sight-reading accuracy was investigated using musical passages with and without tonal information. The passages with tonal information were divided into major- and minor-key condition, to elaborate on the findings of previous studies that have suggested that major keys tend to have more stable internalized representations than minor keys (Delzell, Rohwe, & Ballard, 1999; Harris, 1985; Krumhansl, 1990; Krumhansl, Bharucha, & Kessler, 1982; Vuvan & Schmuckler, 2011; Vuvan, Podolak, & Schmuckler, 2013). The third condition consisted of atonal musical passages, which contain no tonal information. It was hypothesized that sight-reading would be most accurate in the major condition, as sight-reading would be guided by strong expectations. Conversely, it was hypothesized that sight-reading would be the least accurate in the atonal condition, as they would be unable to generate expectations about the music, and would be forced to rely solely on bottom-up processes to guide their sight-reading. Furthermore, the influence of tonality was investigated within monophonic, homophonic and polyphonic textures. It was hypothesized that tonal influences would be the
most obvious in sight-reading the homophonic and polyphonic excerpts, but not the monophonic excerpts. Due to the rich tonal information usually provided by homophonic and polyphonic contexts, sight-reading accuracy for the homophonic-atonal and polyphonic-atonal passages was anticipated to be particularly poor.
Chapter 2

2 Methods

2.1 Participants

Twelve pianists (11 females; mean age = 22 years, $SD = 8.2$ years) participated in this study. Nine of the pianists were students at the University of Toronto Scarborough and received monetary compensation or extra credit in an introductory psychology course for participating. The remaining three participants were recruited by word-of-mouth, and received monetary compensation for their participation. The pianists had a mean of 10.2 years ($SD = 3.4$ years) of private piano instruction, a mean of 15.3 years ($SD = 6.4$ years) of playing experience, and a mean of 2.7 years ($SD = 2.8$ years) of formal musical theory instruction. Eight of the participants completed examinations through the Royal Conservatory of Music (RCM), the leading institution for music education in Canada (mean level achieved = 9.375; $SD = 1.3$ levels). Of the remaining four participants, two completed examinations outside of Canada (in Taiwan), and two participants reported never having taken any formal examinations.

To be eligible, all participants were required to be comfortable sight-reading at a Grade 7 level according to the standards outlined by the RCM, or at an equivalent level. None of the participants had absolute pitch, all had normal or corrected-to-normal vision, and normal hearing.

2.2 Apparatus

Participants performed on a Yamaha S-80 full-sized and weighted electronic keyboard. The keyboard was interfaced to an HP Pro 3400 Microtower PC, with a 3.30 GHz Intel Core processor using a Digidesign Mbox 2 Pro digital recording interface. All performances of the
experiment were recorded both in MIDI and live audio format using Sonar 8.5 Studio software (Cakewalk, 2009). The experimenter and the participant each wore a pair of Sennheiser HD 280 pro headphones to hear the participants’ sight-reading performances.

2.3 Materials and Design

The sight-reading materials were derived from chorales written by Johann Sebastian Bach and edited by Albert Riemenschneider (Riemenschneider, 1941). Twenty-four chorales were chosen, with four-bar passages excerpted from each chorale. This set of chorales was then subdivided into four groups of six, corresponding to four different musical texture conditions: (1) monophonic played by the right hand (RH monophonic), (2) monophonic played by the left hand (LH monophonic), (3) homophonic and (4) polyphonic. An example of the musical stimuli used is shown in Figure 2.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Example of an (a) atonal, (b) major, and (c) minor version of a polyphonic musical excerpt.}
\end{figure}
Of the six chorales presented within each texture condition, three had a 3/4 time signature, and three had a 4/4 time signature, three of the chosen chorales had flat key signatures, and the other three had sharp key signatures, and three of the chorales were originally in major keys whereas the remaining three chorales were originally in minor keys. These manipulations were adopted to ensure that there were no confounds based on a specific time signature, key signature, or transposition, influencing pianists’ performance of these excerpts. A full list of descriptions of the chorales used in each texture condition can be found in Table 1.

Each of the twenty-four passages was then rewritten to be major, minor and atonal (i.e., keyless). Care was taken to ensure that all versions of the excerpts adhered to all formal rules of classical composition as outlined in Aldwell, Schachter and Cadwallader’s (2011) textbook of harmony and voice leading. This ultimately produced seventy-two sight-reading passages in all, divided into three conditions: (1) major, (2) minor, and (3) atonal. Furthermore, dissonant chords (such as augmented or diminished chords) were avoided when writing the atonal excerpts, to avoid confounds based on the types of chords used in the homophonic-atonal and polyphonic-atonal excerpts. Furthermore, none of the scores explicitly indicated a key signature.

There is evidence suggesting that greater numbers of accidentals within a score result in poorer sight-reading performance (Goolsby, 1989). If key signatures had been used, the atonal passages would have inherently possessed a greater number of accidentals in the score due to their increased chromaticism. Therefore, all accidentals were written directly in the score instead (see Figure 2). Furthermore, the accidentals within each excerpt were homogenous; that is, sharp and flat accidentals never occurred in the same passage, and there were no natural, double-sharp or
double-flat accidentals used in any of the excerpts. These manipulations were adopted to ensure that there were no confounds based on the visual complexity of the score.

Table 1. Descriptions for each sight-reading passage used in the experiment.

<table>
<thead>
<tr>
<th>Passage</th>
<th>Chorale number</th>
<th>Time signature</th>
<th>Accidentals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyphonic 1</td>
<td>155</td>
<td>3/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Polyphonic 2</td>
<td>30</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>Polyphonic 3</td>
<td>328</td>
<td>4/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Polyphonic 4</td>
<td>109</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>Polyphonic 5</td>
<td>243</td>
<td>3/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Polyphonic 6</td>
<td>211</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>Homophonic 1</td>
<td>278</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>Homophonic 2</td>
<td>153</td>
<td>4/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Homophonic 3</td>
<td>90</td>
<td>3/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Homophonic 4</td>
<td>96</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>Homophonic 5</td>
<td>178</td>
<td>3/4</td>
<td>Flats</td>
</tr>
<tr>
<td>Homophonic 6</td>
<td>153</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>RH-Monophonic 1</td>
<td>37</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>RH-Monophonic 2</td>
<td>50</td>
<td>4/4</td>
<td>Flats</td>
</tr>
<tr>
<td>RH-Monophonic 3</td>
<td>36</td>
<td>4/4</td>
<td>Flats</td>
</tr>
<tr>
<td>RH-Monophonic 4</td>
<td>44</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>RH-Monophonic 5</td>
<td>47</td>
<td>3/4</td>
<td>Flats</td>
</tr>
<tr>
<td>RH-Monophonic 6</td>
<td>19</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>LH-Monophonic 1</td>
<td>48</td>
<td>4/4</td>
<td>Flats</td>
</tr>
<tr>
<td>LH-Monophonic 2</td>
<td>62</td>
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<td>Flats</td>
</tr>
<tr>
<td>LH-Monophonic 3</td>
<td>7</td>
<td>4/4</td>
<td>Sharps</td>
</tr>
<tr>
<td>LH-Monophonic 4</td>
<td>28</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
<tr>
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<tr>
<td>LH-Monophonic 6</td>
<td>18</td>
<td>3/4</td>
<td>Sharps</td>
</tr>
</tbody>
</table>

To verify the presumed tonality (or atonality) of these different versions of the excerpts, the Krumhansl-Schmuckler (K-S) key-finding algorithm (Krumhansl, 1990; Schmuckler &
Tomovski, 2005) was applied to each passage. The algorithm accurately identified the key of the major and minor versions of each passage, and was unable to identify a single dominant key for the atonal versions (all key correlations were below 0.6).

Each participant was assigned eight passages from each of the three tonality conditions (i.e., major, minor, and atonal) to sight-read, for a total of twenty-four passages. For each condition, the eight passages were further divided into four conditions of texture, which included two polyphonic, two homophonic, two RH monophonic and two LH monophonic pieces. Thus, the experiment utilized a design with two within-subject variables, texture and tonality. Participants did not play two versions of the same passage to avoid any interference effects that might be caused by the transposition.

2.4 Procedure

Before the experimental session, participants signed a consent form, and filled out a brief survey inquiring about their age, demographic information, as well as prior musical experiences (see Appendix A for the complete questionnaire). The experiment and the nature of the passages to be sight-read were explained, and participants subsequently began the experimental task. Participants were asked to pick a comfortable andante (“walking pace”) tempo that was not too slow, and that in the event of a mistake, they were asked to try and avoid restarting the passage from the beginning. At the beginning of every passage to be sight-read, participants were allowed to visually assess the passage for as long as necessary without physically playing anything on the piano. Immediately after sight-reading a passage, participants were asked whether they were familiar with the passage. None of the participants were familiar with any of the excerpts used in this study. Upon completion of the experiment, participants were debriefed.
regarding the purpose of the study, and compensated accordingly for their time. The entire experiment took approximately an hour to complete.
Chapter 3

3 Results

One sight-reading excerpt was omitted from the analysis due to problems with its recording. The erroneously played notes within each of the remaining 278 excerpts were counted. A note was considered to be in error if it was played in place of a correct one, if it was played in the wrong order within a chord, or if it was omitted altogether during sight-reading. Furthermore, any note that was initially played correctly but repeated thereafter was not considered as an error. However, if an erroneously played note was repeated, it was counted as an additional error. The total number of errors was then divided by the total number of notes played by the participant (repeated notes included). The percentages of note errors of all the excerpts were submitted to a 3 × 4 repeated-measured analysis of variance (ANOVA) that treated tonality (major/minor/atonal), and texture (polyphonic/homophonic/RH monophonic/LH monophonic) as within-subject variables. An alpha criterion of .05 was used for all statistical comparisons.

The ANOVA revealed a significant main effect of texture, $F(3, 69) = 30.76$, $MSE = .009$, $p < 0.001$, $\eta_p^2 = .572$. Multiple Bonferroni-corrected comparisons showed that this was due to a significantly larger proportion of errors played in the polyphonic condition than in the RH monophonic, $t(23) = .7.483$, $p < .001$, and LH monophonic, $t(23) = 6.804$, $p < .001$, conditions, as well as a significantly larger proportion of errors played in the homophonic condition than in the RH monophonic, $t(23) = 5.671$, $p < .001$, and LH monophonic, $t(23) = 6.519$, $p < .001$, conditions; Figure 3 presents the means and standard errors for these effects. The analysis also revealed a significant main effect of tonality, $F(2, 46) = 4.278$, $MSE = .012$, $p = .020$, $\eta_p^2 = .157$. Multiple Bonferroni-corrected comparisons showed that this was due to a significantly larger proportion of errors played in the atonal condition than in the major condition $t(23) = .2.750$, $p =$
.033; Figure 4 presents the means and standard errors for this effect. The ANOVA did not reveal a significant interaction between texture and tonality, $F < 1$.

Figure 3. Percent errors for polyphonic, homophonic, right-hand (RH) monophonic and left-hand (LH) monophonic excerpts. For this and all following figures, * = $p < .05$, ** = $p < .01$, *** = $p < .001$. 
Since there was a main effect of tonality, the notes in error within each excerpt were further coded as diatonic (i.e., belonging to the specific major or harmonic minor key of the excerpt) or non-diatonic in nature. This was done only for the major and the minor excerpts, since there was a clearly defined key in each, unlike the atonal excerpts. Furthermore, this distinction was applied only to the errors in which erroneous notes replaced correct ones. For the major excerpts, 72% of the errors were diatonic, whereas for the minor excerpts, 49% of the errors were diatonic. A sign test by subject confirmed significantly higher frequencies of diatonic errors than non-diatonic errors in the major condition (p = 0.05) when compared to the chance estimate of 7:12.
(number of diatonic pitches: number of chromatic pitches across the entire frequency range).

Another sign test was conducted for the minor condition, which showed there was a significantly higher frequency of non-diatonic errors than expected (p = 0.05).

As mentioned earlier, the K-S key-finding algorithm (Krumhansl, 1990; Schmuckler & Tomovski, 2005) was applied to each atonal excerpt to verify its presumed atonality. As a follow up, the ninety-six atonal excerpts played across all participants were resubmitted to the K-S key-finding algorithm to determine whether any of the participants’ performances were biased towards a tonal center. The K-S algorithm was able to identify a dominant key for thirty-one of these atonal sight-reading performances. That is to say, the pitch-class distributions for thirty-one of these atonal performances, weighted by their durations, correlated with at least one of the twenty-four individual key profiles (twelve major and twelve minor key profiles) above r = 0.6.

To determine whether these shifts toward tonality were significant, a one-sample t-test was conducted between the mean of the highest key correlations of the performed excerpts (averaged by participant) and the mean of the highest key correlations of the original atonal excerpts. The results showed a significant difference, t(11) = 2.281, p = .043, suggesting that participants’ performances of atonal pieces were significantly biased towards a tonal center.

It is important to note that the variables that were controlled within-subject (time signature, accidental type, and mode of the original chorale), were submitted to a 2 × 2 × 2 repeated-measures ANOVA. The results showed no main effects (p < .05), but there were significant two-way interactions between time signature and original mode, F(1, 11) = 13.973, p = .003, as well as accidental type and original mode, F(1, 11) = 5.030, p = 0.046). The three-way interaction was not significant (p < .05). Since there were no significant main effects found, and there is no
logical way of interpreting the two-way interactions, these three variables were excluded from the prior analyses of the tonality and texture variables.

As mentioned, work by Goolsby (1989) has suggested that the number of accidentals in a score has a direct effect on the accuracy of performance. For each of the original excerpts, the frequencies of printed accidentals (i.e., accidental markings that appear in the score), implied accidentals (i.e., the accidentals that are not directly printed in the score, but are implied by a printed accidental preceding it within a bar), and total accidentals (i.e., both printed and implied accidentals) were counted. These frequencies were then divided by the total number of notes that occurred in the excerpt. Three separate correlations were then performed on the proportion of note errors with the proportion of printed accidentals in a score, the proportion of implied accidentals, and the proportion of total accidentals in the score. None of these correlations were significant, suggesting that the frequency of accidentals did not contribute significantly to the errors made by participants.
Chapter 4

4 Discussion

The present study provides compelling evidence suggesting that knowledge of the tonal hierarchy plays a role in sight-reading. In line with the proposed hypotheses, pianists performed the major excerpts with greater accuracy than the atonal excerpts when controlling for the mode of the original chorales, accidental types and frequencies, as well as time signature. Furthermore, the results indicated that, for the major excerpts, the errors made were more likely to be diatonic than non-diatonic, providing a clear demonstration of how pianists’ expectations might have contributed to their sight-reading performance. Follow-up analyses could determine whether the distributions of these errors directly map on to the key profiles from Krumhansl and Kessler’s (1982) probe-tone experiments, which could provide even more compelling evidence of tonality acting as a critical factor in sight-reading.

Interestingly, these results did not extend to the minor excerpts. There were no significant differences found between the accuracy of sight-reading performance between the minor and major or atonal excerpts. Furthermore, unlike in the major excerpts, the errors made within the minor excerpts did not seem to be as biased towards diatonicism. This is in line with the aforementioned research that has found that has shown listeners’ cognitive representations of the minor tonality tend to be weaker than that of the major tonality. It is possible that the minor tonality does exert as much of an influence during sight-reading since three different versions of the minor tonal structure (natural minor, harmonic minor, and melodic minor) can be represented simultaneously (Vuvan, Prince, & Schmuckler, 2011). Therefore, the extent to which knowledge of the minor tonality is used during sight-reading can be more closely examined with a follow-up study directly comparing sight-reading performances of natural, harmonic, and melodic minor
excerpts. Finally, the results indicated that participants’ atonal performances seemed to be biased toward a tonal center. However, it is important to consider the fact that the present study only scrutinized global shifts towards tonality. Local tonality can be investigated by applying the K-S key-finding algorithm to smaller windows across performances. This way, the changes in tonality (or atonality) could be tracked over time, providing a more accurate assessment of how sight-reading performances are biased towards tonality.

A limitation to the present study was the fact that there were no manipulations or measurements of the temporal aspects of the music. Participants were free to choose their tempo, and there were no attempts at assessing rhythmic accuracy across tonality and texture. As a result, the present study cannot address the influence of metrical hierarchies on sight-reading, or the influence of the interrelations between the dimensions of pitch and time. This interrelation been thoroughly researched within music perception and cognition, but not in sight-reading. Furthermore, there is an ongoing debate about whether or not the dimensions of pitch and time are actually related or independent (Prince, Schmuckler, & Thompson, 2009). Naturally, then, the next step is to scrutinize the interaction of rhythm and tonality within sight-reading in an attempt to reconcile some of the conflicting results. One way of measuring this would be to compose sight-reading materials in which the pitches occurring on the strong beats of the excerpt were tonal in relation to each other, whereas the pitches occurring on the weak beats of the excerpt were atonal.

A final future direction of the research presented here will be to utilize eye-tracking technology. Recent advances in eye-tracking technology have made it possible to overcome many of the issues surrounding ecological validity in early studies. The development of mobile eye-trackers has made it possible to measure eye movements in real time and to generate point-of-gaze data with respect to the working environment using head-mounted scene cameras. Therefore,
musicians no longer need to be restricted in their movements, as is the case with older eye-tracking technology, allowing them to receive proper visual feedback while performing. Despite these advances, the research in eye movements and music reading is still underdeveloped relative to other research programs in music cognition and perception. Madell and Hébert (2008) have brought forth a convincing argument for the lack of research in this area. They argue that “the lack of focus on musical structure and convincing links between structure and eye movements makes comparisons across studies difficult and isolates music reading studies from other music cognition and perception studies” (Madell & Hébert, 2008). They recommend that in order for research in eye movements and music reading to move forward, “research in the relationships between musical structure and eye movements needs to shift focus from the coarse-grained properties to more carefully controlled fine-grained (i.e., structural) properties of music on the page.” Thus, applying mobile eye-tracking technology to the paradigm used in the present study would be one step toward remedying this issue, as it could provide a wealth of data on the patterns of eye movements as a function of not only tonal variation, but textural variation as well.

In conclusion, there is still much to be learned about the various factors that influence the cognitive processes involved in sight-reading. The results of the present study have merely begun to scratch the surface; however, future investigations into this line of work could be incredibly useful in understanding the fundamental aspects of sight-reading, tonality, and music cognition in general.
References


Appendix A. Musical background Questionnaire

Subject Number: _____

Thank you for taking the time to complete this questionnaire and experiment. Please fill out the following questions to the best of your ability. If you have any questions, please do not hesitate to ask the researcher!

General Questions

1. Gender: M  F

2. Age:

3. Do you have perfect pitch? Y  N

*Note: If you do have perfect pitch, please inform the researcher immediately. If not, please continue to the next questions.

4. a) Have you ever participated in any other music experiments? Y  N

   b) If so, which ones? (Please list them)

Musical Experience

1. How many years have you been playing piano? _____

2. Please check off the types of formal instruction you have received for piano, and indicate the number of years that you received this training:

<table>
<thead>
<tr>
<th>Type of Formal Instruction</th>
<th>Years of Training</th>
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<tbody>
<tr>
<td>Private Lessons</td>
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<tr>
<td>Group Class</td>
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</tr>
<tr>
<td>Suzuki Method</td>
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</tr>
<tr>
<td>In-School Course (Middle School)</td>
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<tr>
<td>In-School Course (High School)</td>
<td></td>
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<tr>
<td>In-School Course (College)</td>
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</tbody>
</table>
3. How many years have you studied music theory **formally** (at a music school, university, or privately with a teacher)? ______

4. How many years have you studied ear training **formally**? ______

5. a) Have you completed any formal exams in theory and performance for piano through the Royal Conservatory of Music (RCM)? Yes No (Please circle one)

   b) If so, please list them below:

   *Note: If you have taken consecutive examinations (i.e., Grade 1, 2, 3, 4, 5, 6), please list the highest level of examination that you have completed.

6. Have you taken any other formal examinations for theory or performance through other institutions? Yes No (Please circle one)

   b) If so, what examinations were they, and what institution(s) did you take these exams through? Please list them below, and be as specific as possible:

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<thead>
<tr>
<th>Examination &amp; Description</th>
<th>Institution</th>
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7. What other instruments do you play (including voice)? Please list them below, and indicate (i) how many years you have been playing each of these instruments, (ii) how many years of formal instruction you have received for these instruments, and (iii) what was the nature of this instruction? (Please refer to Question 2 for the instruction types)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Years Playing</th>
<th>Years of Formal Instruction &amp; Type</th>
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8. Please list the formal exams in performance have you passed on all of these instruments, and which institution(s) that administered these examinations. Please be as specific as possible:

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<th>Examination &amp; Description</th>
<th>Institution</th>
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9. How many hours a week do you currently play/practice piano? _____

10. How many hours a week do you currently play/practice other instruments? _____

11. How many hours a week do you currently practice sight-reading for piano? _____

12. How many hours a week do you currently practice sight-reading on other instruments? _____

13. Do you play/practice atonal music regularly? If so, how many hours per week? _____
14. a) Do you teach piano? If so, how many years have you been teaching for? _____
   b) What do you teach, and at what level of piano do you teach?

15. a) Do you teach any other instruments? If so, how many years have you been teaching
       for? _____
   b) What do you teach, and at what level do you teach?

16. Do you compose music? If so, how long have you been composing, and what types of music?
    Please be as specific as possible.

17. Do you currently perform music regularly? If so, what instruments do you perform, what is
    the nature of your performance (i.e., in a band, solo, etc.), and how often do you perform? Please
    be as specific as possible.

18. In each category below, mark about how many hours a week you spend listening to each type
    of music.
    a) Classical (Tonal) _____  h) Rhythm & Blues _____
    b) Classical (Atonal) _____ i) Rap & Hip-Hop _____
    c) Jazz _____  j) Reggae _____
    d) Rock _____  k) Country _____
    e) Choral _____  l) Folk _____
    f) Electronic _____  m) Pop _____
    g) Other (Please Specify)