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A preliminary study: is the metronome harmful or helpful?

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Abstract

The metronome is a frequently used time-keeping tool in music instrument practice. However, if its speed is set beyond a comfortable level for the performer, their eye movement (EM) patterns can betray pressure that might have been placed on the visual processing system. The patterns of the eyes moving forward or back, (saccades); when the eye stops between saccades to take in visual information, (fixations) and/or the time taken to programme a saccade (saccadic latency), are indicative of processing ability and differ with expertise. What is not known is how various levels of speed demand might affect the EM patterns of musicians with differing sight-reading abilities.

This study measured the EM patterns of expert and non-expert music sight-readers. Musical excerpts were played on a keyboard – initially at the individual's fastest speed ensuring accuracy and then at a metronome setting of 120MM.

The study showed that imposing excessive relative speed demands on less skilled sight-readers resulted in an inability to sustain performance. While this result might be expected, examination of the EM patterns of the experts indicated that smaller speed increments relative to their fastest accurate speed, resulted in less processing stress.

Key words*:* sight-reading, piano, expertise, eye movements, cognition, metronome

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Introduction

The metronome is a time-keeping device that emits clicks or tones at a prescribed rate. It is valuable for teaching the rudiments of pulse and metre and can also be used as an adjunct to mastering notation (Miller, 2012). There is a general consensus that the metronome is an indispensable tool for helping novice percussionists keep in time, but there is little advice or few suggestions given as to how best to use it other than to simply use it (Falle, 2011).

Recent research has shown that, as the level of a musician's expertise increases, so too does the use of the metronome in their personal practice. The authors also showed that metronome use related to higher scores in a given performance grade examination. In addition, its use significantly increased at Grade 6 level and beyond (Hallam, Rinta, Varvarigou & Creech, 2012). Conversely, they showed that there is minimal use of the metronome up to 6th grade level. It is surprising then, that the metronome's importance is stressed in early percussion instruction albeit with little specific direction and features in the practice patterns of more experienced musicians, but appears to be somewhat overlooked in other early instrumental teaching. All musicians – not just percussionists – need to keep accurate time.

Accuracy of time-keeping can be judged by measuring the asynchrony threshold. It is the difference between when a rhythmic series of sounds occur and how closely an individual can tap along with that rhythm. A person with a low threshold can tap more accurately to a beat. That is, there is a smaller time difference between the onset of the beat and the actual tap than for a person with a higher threshold. In an ensemble setting particularly, it is important that musicians are synchronised with their conductor and with one another.

Differences in the asynchrony threshold have been found, not only between musicians and non-musicians, but between the types of instrument played and the players' level of expertise (Krause, Pollok & Schnitzler, 2010). It was found that professional pianists and percussionists had equivalent asynchrony thresholds while amateur pianists and non-musicians had increasing higher thresholds and were also less sensitive to timing changes (Ehrle & Samson, 2005; Krause et al., 2010; Repp, 2010). Synchronising was also found to be superior in those musicians who had commenced training before the age of 7 and that this earlier trained group could also more accurately synchronise with a visual stimulus (Watanabe, Savion-Lemieux & Penhune, 2007). When comparing the ability to synchronise a tap with an auditory stimulus or a visual stimulus, it was found that that participants were able to synchronise more accurately with auditory over visual (Repp & Penel, 2002).

Not only is performance skill linked with superior asynchrony thresholds and use of the metronome by higher grades in private practice, differences are also evident in the EM patterns of music sight-readers of different expertise levels (Kinsler & Carpenter, 1995; Sloboda, 1977; Wurtz, Mueri & Wiesendanger, 2009). These patterns are similar to those found in the literature on text reading. For example, skilled text readers are more efficient because they utilise shorter duration fixations and execute fewer regressive saccades (Underwood, Hubbard &Wilkinson, 1990). That is, the expert can process visual information using fewer backward EMs with the dwell time between EMs, which is used to gather such information, being of shorter duration. This phenomenon is known as 'chunking'. It is a characteristic of an experts' ability to group individual items into fewer aggregates for efficiency of processing (Ashby et al., 2005; Gobet et al., 2001; Heller, 1982; Kowler, 2011; Legge, 2007; Meseguer et al., 2002; Rayner, 1998; Rayner, Chace, Slattery & Ashby, 2006; Truitt, Clifton, Pollatsek & Rayner, 1997; Underwood et al., 1990) with the subsequent increased speed that is characteristic of expertise in general (Bilalic, Langner, Ulrich, & Grodd, 2011; Ericsson, Krampe, Tesch-Romer, 1993; Ericsson, Roring, & Nandagopal, 2007; Farrington-Darby & Wilson, 2006; Gauthier & Bukach, 2007). Chunking EM patterns have also been demonstrated in musicians as they read score (Furneaux & Land, 1999; Goolsby, 1987; Kinsler & Carpenter, 1995; Schmidt, 1981; Sloboda 1974, 1977; Truitt et al., 1997; Wolf, 1976; Wurtz et al., 2009). Conversely, novice text readers back-track and re-fixate more often to assistance lexical and semantic processing (Rayner et al., 2006) and is indicative of reading comprehension difficulties (Underwood et al., 1990).

When functional visual parameters are imposed on print stimuli, the features of EMs change. For example, when print is blurred, the number, direction, speed and/or latency, of the forward and regressive EMS, (saccades), will change. When more features such as size and spacing are changed the dwell time, (fixation), characteristics of number and/or duration are affected (Legge, 2007). Recent research demonstrated that when musicians read score with disrupted visual notation, such as the absence of bar lines and irregularity of note spacing, saccadic latency was significantly increased in expert sight-readers only (Arthur, Khuu & Blom, 2016). Increased saccadic latency is a response to visual uncertainty (Cameron, 1995) and this is suggestive of processing stress in the expert group. This is because 'chunking' had been disrupted when the stimuli did not conform to visual expectation

– visual stress. In a similar way, little is known about processing stresses that might occur when musicians have timing pressure imposed upon performance by using a metronome and how this might affect EM patterns.

The present study investigated the EM patterns of expert and non-expert music sight-readers of keyboard scores as they read and played musical excerpts initially without and then with the aid of a metronome. Fixation duration, the number and speed of forward and regressive saccades and their latency were measured. It was hypothesised that EM patterns would show evidence of cognitive processing load when excessive timing demands are imposed suggesting a point, beyond which, the metronome could be more harmful than helpful.

Methods

Participants

Following the granting of ethics approval from an Australian Human Research Ethics Advisory Committee to perform the study, participants were recruited from within a university student body and reimbursed for their time. Consideration for inclusion in the study was based upon an individual self-selecting their ability to perform, on a keyboard, a sample sight-reading melody as it appeared on the recruitment poster (see Figure 1). Each observer wore full visual correction if applicable and was capable of 6/6 (normal) vision or better at a viewing distance of 60cm.

Eighteen subjects were recruited. Expertise in sight-reading was assigned according to the successful performance of a 6th grade AMEB sight-reading assessment. (The Australian Music Examinations Board (AMEB) provides graded assessments of student achievement in musical instrument performance, singing, music theory, musicianship, speech and drama.)

This level had been proposed as a benchmark in a previous study (Waters, Townsend & Underwood, 1998). 8 subjects were placed in the expert sight-readers' category and 10 in the non-expert accordingly.

Stimulus

4-bar individual melodies were composed (see Figure 1 and Appendix 1), each written in the treble clef, to be played by the right hand and limited to white notes only. A single line of music on one stave had previously been found to provide an adequate stimulus to assess expertise (Wong & Gauthier, 2009). The authors found that multiple staves were more likely to measure performance differences rather than the EM characteristics being investigated.

The musical passages were presented with a note head size equivalent to N10 print viewed at 60 cm. This size was chosen as it is twice the size of print deemed to require 'normal' vision in Optometric terms and to fall within the critical print size that allows efficient EMs (Legge, 2007). Due to recruitment limitations and time constraints, only one metronome speed was tested. 120MM, (120 beats per minute), was chosen as it represented the upper end of the 'moderato' speed range and was readily divisible by 60 seconds. As such, there were 2 crotchets per beat, with each musical excerpt, being four bars of 4/4 time, taking 8 seconds to play.

The stimulus viewing distance was calculated by questioning four pianists as to the approximate

Figure 1: A sample musical excerpt.

viewing distance of music when playing a standard upright piano. 60cm was chosen: the range was from 30 to 60cms, with 3 values between 50 and 65cm. A constant distance is required to keep the retinal image size stable while the EMs are being measure. This has long been known to fundamentally affect the performance of EMs (Tinker, 1946).

Procedure

EM data was collected using the Arrington Research 'ViewPoint' USB220 eye tracker, the sampling rate being 220 frames/second. The images were generated using a custom written programme for MATLAB and presented on a linearized 27-inch Mitsubishi Diamond Pro monitor driven at a frame rate of 80Hz (see Figure 2). The tracker was driven by a Hewlett Packard 'Elitebook 8470p' PC (Intel Core i5 2.60GHz processor/8.00GB RAM/16-bit Operating System).

The apparatus consisted of a single infrared camera mounted on a chin and headrest assembly that was mounted on an instrument table. The table was set so that the viewing distance to the screen was 60cm. The participant's height was carefully aligned using a canthus mark that was level with the centre of the computer screen. The camera was then calibrated according to the manufacturer's instructions. Once calibration was successfully performed, a practice session was performed in order for the participant to become familiar and comfortable with the testing process: 4 seconds after a tone sounded, the music stimulus would appear on the computer screen. Participants were instructed to start playing the piece as soon as it appeared on the screen, as quickly and as accurately as possible, without looking down at the hand, without pre-reading and without stopping regardless of errors. After the participant finished playing, a visual noise patch was presented on the screen. The participant was instructed to fixate on it to eliminate any afterimages that may have been generated by the test stimulus and impact on the perception of subsequent stimuli. Sufficient time was given to re-orientate the hands into position, by touch, between presentations. After 6 trials, the full procedure was undertaken, following the same procedure.

In order to ensure that only score reading EMs were being measured, a specific portion of the data set was selected for analysis. For example, variations in the time taken to start playing after stimulus onset or differences in the cessation of reading EMs towards the end of the piece all needed to be eliminated. Therefore, the time that playing commenced, T1, through to the time that playing ceased at the end of bar 3, T2 was used as the sound window for analysis.

The location of T1 and T2 was determined using Fleximusic™ Audio Editor. The sound files were imported and the points on the wave file for T1 and T2 were determined by first filtering for noise and then manually marking the location of T1 and T2. This process was found to be repeatable to within 0.05 second. Once T1 and T2 were known in relation to the length of the sound file,

Figure 2: Experimental set-up showing piano keyboard, computer display and eye tracker camera

it was then possible to calculate the number of samples between points T1 and T2. Therefore, EM parameters calculated between T1 and T2 pertain only to the time period of interest: when the music was being read.

Each participant was required to sight-read and play the specifically composed musical passages of 4 bars duration as quickly and as accurately as possible – the first pass. Each of these trials consisted of 54 unique pieces – 2 size groups and 3 blur groups, each groups comprising 9 exemplars. These were presented in a randomised order. This process was then repeated – the second pass – using the same 54 pieces, with the participants now instructed to play in time with the metronome set at 120MM.

Fixation (when the eye stops to take in visual information) and saccade (the EM from one fixation to the next) characteristics were measured and compared between the two performances and analyzed using a purpose-written Matlab™ code.

Results

The results for the 9, N10/No Blur performances with and without metronome conditions were extracted from each participant's complete data set (see Appendix 1). Separate two-way ANOVA and paired t-tests were performed to determine if specific effects existed between expert and non-expert music sight-readers when a metronome set at 120MM was imposed and significance was assigned at the 0.05 level. The results were summarized in Figure 3. The No Metronome and Metronome Conditions were plotted against Total Time (Figure 3a), Number of Fixations (Figure 3b), Fixation Duration, (Figure 3c), Saccadic Latency (Figure 2d), Number of Forward Saccades (Figure 3e), Forward Saccade Speed (Figure 3f), Number of Regressive Saccades (Figure 3g) and Regressive Saccade Speed (Figure 3h) when performing musical excerpts from T1 to T2 for expert and non-expert music sight-readers. Error bars = SEM.

An overall expertise effect for Total Time was found: $F(1,31) = 10.86$, $p=0.0025$. Experts performed significantly faster in both conditions: $M_{MET} = 6$ secs, $SD = 0.00$, $M_{NoMET} = 6.397$ secs, $SD = 0.71$ than the non-experts: $M_{MET} = 7.483$ secs, $SD = 1.39$, $M_{NoMET} = 8.909$ secs, $SD = 2.84$. Although both groups were forced to play faster, there was no significant effect for metronome: $F(1, 31) = 3.263$, $p = 0.08$ or interaction between expertise and metronome: $F(1,31) = 1.595$, $p = 0.22$.

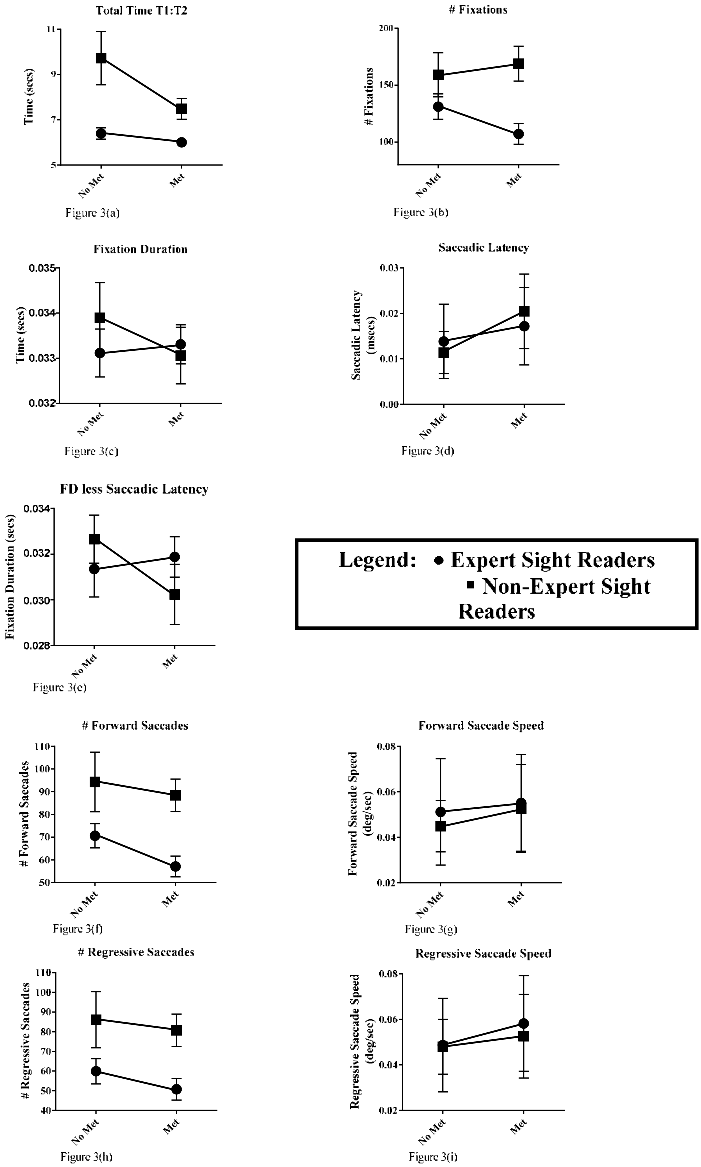
There was an overall expertise effect for the number of fixations: $F(1,30) = 10.48$, $p=0.003$. The experts executed significantly fewer fixations: $M_{MET} = 100$, $SD = 15.44$, $M_{NoMET} = 128$, $SD = 32.63$ while the non-experts barely changed: $M_{MET} = 159$, $SD = 40.31$, $M_{NoMET} = 159$, $SD = 58.18$ when the metronome was introduced. The introduction of the metronome caused the opposite response from each group, but there was no significant metronome effect: $F(1, 30) = 0.5243$, $p = 0.42$ or interaction between expertise and metronome: $F(1,30) = 1.892$, $p = 0.18$ was found. However, the number of fixations was significantly different between the groups in the metronome condition: $t(1,30) = 3.239$, $p = 0.02$.

The groups also responded in the opposite direction for Fixation Duration. However, the data revealed no significant expertise or metronome effects: $F(1,32) = 0.1724$, $p = 0.68$ and $F(1,32) = 0.2554$, $p = 0.62$ respectively.

Both groups increased saccadic latency, but no significant effects were found. Expertise: $F(1, 30) = 0.0028$, $p = 0.96$, Metronome: $F(1,30) = 0.69$, $p = 0.41$ and Interaction: $F(1,30) = 0.1470$, $p = 0.70$ respectively.

The non-experts performing significantly more EMs – forward and regressive – than the experts. Overall expertise effects were found for the number of forward saccades: $F(1,31) = 9.779$, $p = 0.004$. The non-experts performed significantly more forward saccades: $M_{MET} = 84$, $SD = 19.95$, $M_{NoMET} = 84$, $SD = 29.28$, than the experts: $M_{MET} = 57$, $SD = 12.87$, $M_{NoMET} = 71$, $SD = 15.12$. There was no significant metronome effect: $F(1,31) = 0.4381$,

Figure 3: The No Metronome and Metronome Conditions were plotted against Total Time (Figure 3a), Number of Fixations (Figure 3b), Fixation Duration, (Figure 3c), Saccadic Latency (Figure 2d), Number of Forward Saccades (Figure 3e), Forward Saccade Speed (Figure 3f), Number of Regressive Saccades (Figure 3g) and Regressive Saccade Speed (Figure 3h) when performing musical excerpts from T1 to T2 for expert and non-expert music sight-readers. Error bars = SEM.



p = 0.51: and no interaction between expertise and metronome for forward saccades: F (1,31) = 1.465, p = 0.24.

Similarly, for regressive saccades a significant expertise effect was found: F (1,31) = 7.801, p = 0.009 with no significant metronome or interaction effects: F (1,31) = 0.0478, p = 0.83 and F (1,31) = 0.8272, p = 0.37 respectively. The non-experts performed significantly more regressive saccades: M_{MET} = 76, SD = 21.59, M_{NoMET} = 75, SD = 30.59, than the experts: M_{MET} = 51, SD = 15.49, M_{NoMET} = 60, SD = 18.20.

Forward saccade speeds were not significantly affected by the metronome for either expertise group and demonstrated large with group variations. Consequently, there were no significant expertise or metronome effects or interactions found: F (1,31) = 0.0546, p = 0.82, F (1,31) = 0.0990, p = 0.76 and F (1,31) = 0.0107, p = 0.92 respectively.

A similar pattern was found for regressive saccade speed. No significant expertise or metronome effects or interactions found: F (1,31) = 0.0314, p = 0.86, F (1,31) = 0.1563, p = 0.695 and F (1,31) = 0.0186, p = 0.89 respectively.

Discussion

The purpose of this study was to explore the EM responses of musicians as they read music score. Each participant's original playing speed was their fastest and most accurate possible. The metronome setting of 120MM forced both groups to play faster and the EM patterns revealed that a degree of interference had occurred. However, it must be acknowledged that the experts were not pushed to the same equivalent relative speed, nor were the non-experts given the opportunity to perform at the smaller speed increment. As previously mentioned, this study formed part of a larger work and was subject to recruitment limitations and time constraints for completion. Ideally, testing sequential speed increments would need to be done to provide a clearer and more comprehensive picture of the role that expertise might play as opposed to purely processing stress when the metronome is used. Nevertheless, observations can be made from the data available, with implications for instrumental pedagogy and future research studies.

The average time for the non-experts to play from T1 to T2 at their fastest correct speed was 9.7 seconds. When the metronome was set at MM=120, T1 to T2 was then required to be played at 6 seconds. This represented an incremental increase in speed of approximately 58% over their average fastest correct speed to perform from T1 to T2. As a result, it is not surprising that they were pushed beyond their ability to preserve their performance. Different strategies were employed to cope with this performance stress: some played in time for one bar at a time, pausing to process the next bar which was then played at tempo, followed by another pause; some played at 60MM (half the speed); while others ignored the metronome completely. It is, therefore, not surprising that the EM patterns are quite different, if not opposite, to those of the experts at the same speed as well as displaying large within group variations.

The non-expert group increased their speed by increasing the number of fixations while decreasing their duration. The saccades were consequently of shorter duration and therefore, shorter length with longer latencies, although the current results were not significant. This is, characteristic of a 'speed/accuracy trade-off' (Cameron, 1995); where increased errors are allowed in favour of speed. This is similar to findings for text reading where it has been shown that increased processing pressure leads to shorter saccades of less duration that have taken longer to programme (Kowler & Anton, 1987). These results also agree with other researchers' findings of short duration fixations under time pressure for text reading (Gobet et al, 2001; Underwood et al., 1990).

The average time for the experts to play from T1 to T2 at their fastest correct speed was

6.34 seconds. When the metronome was set at MM=120, T1 to T2 was then required to be played at 6 seconds duration. This represented an increase in speed of approximately 6% from their average fastest correct speed to perform from T1 to T2. At this pace, the experts were able to maintain performance. Their EMs showed the opposite response to those of the non-experts; a decrease in the number fixations with an increased duration. This is indicative of saccade cancellation in response to processing stress (Yang & McConkie, 2001) rather than increasing the number of fixations. Regardless, the expert and non-expert groups both had equivalent saccade speeds despite large variations in response within and across both groups. As such, both groups appear to be functionally equivalent.

The results indicated that the expertise groups responded differently to the pressure of keeping up with an imposed timing, but the amount of stress differed compared with their initial speed. Therefore, the conclusion cannot be drawn that the non-expert group would always adopt the same reading strategy regardless of the relative change in speed. That is, the non-expert group may adopt the strategy of saccade cancellation with increased fixation duration if the increase in stress was of an order of magnitude similar to that imposed on the expert group in this study. In the same way, if the expert group was exposed to a more extreme stress they may adopt the speed/accuracy trade-off strategy and perform more EMs that have taken longer to programme with shorter fixation durations. Future studies with smaller incremental changes in speed would resolve this issue.

When considering the research supporting the superior timing skills of percussionists (Ehrle & Samson, 2005; Krause et al, 2010; Repp, 2010), the benefit of early training (Falle, 2011; Watanabe et al., 2007) and that motor control is better guided by auditory information (Repp & Penel, 2002), it seems that the metronome is an exceptionally underutilized tool in general music instrumental instruction. However, the results of the present study suggest that it would be unreasonable to simply set the metronome at a prescribed speed and hope that the student is able to manage to play the piece successfully – especially if that speed is excessively greater than what might be their personally selected speed to ensure accuracy of performance. A 58% increase in speed was imposed on the non-expert group and their performance failed. Despite their slower average time taken to play from T1 to T2, the performances of the non-expert sight-reading group were, nevertheless, accurate at their original speed. Does either expertise group have anything in reserve at this self-selected pace?

A study of typists indicated that their self-selected speed to ensure accuracy was somewhat conservative and approximately 10-20% below potential (Ericsson et al., 2007). It may be reasonable to suggest that this may also be the case for music sight-readers. In the present study, both groups may have initially performed within this buffer. Perhaps it is from *this* point that the metronome rate should be incrementally increased, knowing that players are likely to have 'reserves' at this level. This might explain why the experts were still able to maintain performance as they were not pushed beyond their reserves, while the non-experts were pushed far beyond.

While sight-reading expertise has been demonstrated in the EM patterns of pianists who can correctly perform a 6th Grade sight-reading examination passage (Arthur, 2016) and there is a significantly greater use of the metronome by musicians at and above 6th Grade level (Hallam et al., 2012), it does not follow that using the metronome ensures music sight-reading expertise. Music sight-reading expertise is a multi-factorial endpoint attained after many years of training with extensive theoretical understanding of western art music forms (Ericsson et al., 1993; Hambrick et al., 2014; Meinz & Hambrick, 2010; Repp, 2010). Even so, some will never attain expertise despite extensive hours of deliberate practice (Hambrick et al., 2014). This study does, however, highlight the apparent underutilisation of the metronome in music education and the need for more extensive research into its earlier introduction and systematic use in early instrumental instruction to explore such issues.

In order to better understand how incremental speed changes might affect music sight-readers, future studies could use smaller increases in speed to determine at what percentage increase the performance accuracy is lost and examine how the EM patterns may change at these points. It is not clear from the present study whether the resultant EM patterns were related to expertise or to extreme processing stress regardless of expertise. That is, would the experts show an EM response to that of the non-experts at a metronome setting of MM = 190? Conversely, would the non-experts' response resemble the experts with the metronome set at MM=127?

Analysing EM patterns and comparing them across expertise groups as speed increments are made could also be continued until a point is found where chunking efficiencies are no longer viable. This would conclusively show whether or not the issue is one of expertise or the individual's accuracy buffer. However, after the original playing, known as 'first pass,' has been performed, it has been shown that EMs will be different in any subsequent consecutive passes (Goolsby, 1994). Also, some describe sight-reading as only occurring the first time an unfamiliar piece of music is played while others consider that familiarization with a piece before playing would also constitute a sight-reading task (Lehmann & McArthur, 2002). Second pass effects were minimised in this study as the second pass with the metronome occurred after 54 bespoke melodies were played at first pass. It is, therefore, highly unlikely that any familiarisation had occurred that might influence the EM measures at second pass.

It could be argued that it is really a moot point. Learning to play notated music in the context of instrumental learning will involve multiple passes and EM patterns will change. What this study has supported however, is the concept of the performance buffer. If EM efficiencies break down when an individual is forced to perform beyond that zone may make little difference if the performance outcome is what is being judged. However, knowing that visual processing stress can be induced by imposing excessing speed demands on a student is, at best, counterproductive in their musical journey.

Therefore, based on the results of this preliminary study and knowledge of the performance buffer, the following recommendations are made. The speed at which the playing of a piece is fastest, while maintaining accuracy of performance, is measured. Knowing that this rate is likely to be within the conservative 10-20% performance buffer, the metronome is then set 5% above this initial speed and the piece practiced until fluency is achieved. Further 5% increments are made until the desired level of speed is attained – ensuring accuracy of performance before proceeding to a faster speed.

Conclusion

EM patterns indicated that music sight-readers experienced cognitive load when pushed to perform faster than their fastest accurate speed. The non-experts were pushed well beyond their 10-20% buffer and were unable to maintain a functional performance. The experts were situated well within their 10-20% performance buffer and performed accurately. The resultant EM patterns were opposite those of the non-experts but this may be related to the level of processing stress encountered rather than the level of sight-reading expertise.

From the practical viewpoint of the performance buffer, suggestions for systematic use of the metronome have been made. This may well reflect the intuitive use of the metronome in instrumental teaching and, as such, helps to scientifically ground such practices. In addition, consideration of its earlier and more habitual use in an individual's private practice has been emphasised and areas of further investigation of the relationship between EMs and sight-reading expertise proposed.

Declaration of conflicting interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

Arthur, P. J. (2017). *Piano Music Sight-Reading: The Transfer of Expertise to Non-Musical Domains and the Effect of Visual and Auditory Interference on Performance*. (Doctoral Thesis, University of New South Wales, Sydney, Australia). Retrieved from http://handle.unsw.edu.au/1959.4/57696.

Arthur, P., Khuu, S. & Blom, D. (2016). Music sight-reading expertise, visually disrupted score and eye movements. *Journal of Eye Movement Research, 9*(7):1, 1-12.

Bilalic, M., Langner, R., Ulrich, R. & Grodd, W. (2011). Many faces of chess expertise: Fusiform face area in chess experts and novices. *The Journal of Neuroscience, 31*(28), 10206-10214.

Cameron, E. L. (1995). *Factors Determining the Latency of Saccadic Eye Movements.* (PhD), University of Rochester, New York.

Ehrle, N. & Samson, V. (2005). Auditory discrimination of anisochrony: Influence of the tempo and musical backgrounds of listeners. *Brain and Cognition, 58*, 133-147.

Ericsson, K. A., Krampe, R. T. & Tesch-Romer, C. (1993). The role of deliberate pracrice in the aquisition of expert performance. *Psychology Review, 100*(3), 363-406.

Ericsson, K. A., Roring, R. & Nandagopal, K. (2007). Giftedness and evidence for reproducibly superior performance: An account based on the expert performance framework *High Ability Studies, 18*(1), 3-56.

Falle, B. (2011). *Proposed Methods For Efficiently Attaining The Skills Required For Accurate Time Keeping In Music.* (Bachelor of Music Honours Honours), Edith Cowan University, WA.

Farrington-Darby, T. & Wilson, J. (2006). The nature of expertise: A review. *Applied Ergonomics, 37*, 17-32.

Furneaux, S. & Land, M. F. (1999). The effects of skill on the eye-hand span during musical sight-reading. *Proc Biol Sci, 266*(1436), 2435-2440. doi:10.1098/rspb.1999.0943

Gobet, F., Lane, P. C., Croker, S., Cheng, P. C., Jones, G., Oliver, I. & Pine, J. M. (2001). Chunking mechanisms in human learning. *Trends Cogn Sci, 5*(6), 236-243.

Goolsby, T. (1987). *The Parameters of Eye Movements in Vocal Music Reading.* ProQuest Dissertations and Theses.

Goolsby, T. (1994). Eye Movement in Music Reading: Effects of Reading Ability, Notational Complexity, and Encounters. *Music Perception: An Interdisciplinary Journal, 12*(1), 77-96.

Hallam, S., Rinta, T., Varvarigou, M. & Creech, A. (2012). The development of Practice strategies in young people. *Psychology of Music, 40*(5), 652-680.

Hambrick, O. F., Altmann, E., Meinz, E., Gobet, F. & Campitelli, G. (2014). Deliberate practice: Is that all it takes to become an expert? *Intelligence, 45*, 34-45.

Kinsler, V. & Carpenter, R. H. S. (1995). Saccadic eye movements while reading music. *Vision Research, 35*(10), 1447-1458. doi:http://dx.doi.org/10.1016/0042-6989(95)98724-N

Kowler, E. (2011). Eye movements: the past 25 years. *Vision Res, 51*(13), 1457-1483.

Kowler, E. & Anton, S. (1987). Reading Twisted Text: Implications for the role of Saccades. *Vision Research, 27*(1).

Krause, V., Pollok, B. & Schnitzler, A. (2010). Perception in action: The impact of sensory information on sensorimotor synchronization in musicians and non-musicians. *Acta Psychologica, 133*, 28-37.

Legge, G. E. (2007). *The Psychophysics of Reading*. New Jersey, USA: Lawrence Erlbaum Associates, Inc.

Legge, G. E. (2007). *Psychophysics of Reading in Normal and Low Vision*. Mahwah, New Jersey, USA.: Lawrence Erlbaum Associates, Inc., Publishers.

Meinz, E. & Hambrick, D. (2010). Deliberate Practice Is Necessary but Not Sufficient to Explain Individual Differences in Piano Sight-Reading Skill: The Role of Working Memory Capacity. *Psychological Science, 21*(7), 914-919.

Miller, B. A. (2012). Rhythmic Instruction From Square One: A Constructivist Teacher and Her Metronome. *General Music Today, 26*(1), 19-26.

Rayner, K., Chace, K., Slattery, T. & Ashby, J. (2006). Eye Movements as Reflections of Comprehension Processes in Reading. *Scientific Studies of Reading, 10*(3), 241-255.

Rayner, K., Fischer, M. & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Research, 38*(8), 1129-1144

Repp, B. (2010). Sensorimotor synchronization and perception of timing: Effects of music training and task experience. *Human Movement Science, 29*, 210-213.

Repp, B. & Penel, A. (2002). Auditory Dominance in Temporal Processing: New Evidence From Synchronization With Simultaneous Visual and Auditory Sequences. *Journal of Experimental Psychology: Human Perception and Performance, 28*(5), 1085–1099.

Sloboda, J. (1974). The Eye-Hand Span: An Approach to the Study of Sight Reading. *Psychology of Music, 2*(4), 4-10.

Sloboda, J. (1977). Phrase Units as Determinants of Visual Processing in Music Reading. *Br J Psychol, 68*, 117-124.

Schmidt, F. (1981). *Movement Patterns of Woodwind Instrument Performers while Sight Reading Music.* Proquest Dissertations and Theses

Tinker, M. A. (1946). The study of eye movements in reading. *Psychol Bull, 43*, 93-120.

Truitt, F., Clifton, C. J., Pollatsek, A. & Rayner, K. (1997). The Perceptual Span and the Eye-Hand Span in Sight Reading Music. *Visual Cognition, 4*(2), 143-161.

Underwood, G., Hubbard, A. & Wilkinson, H. (1990). Eye fixations predict reading comprehension: the relationships between reading skill, reading speed, and visual inspection. *Lang Speech, 33 (Pt 1)*, 69-81.

Watanabe, D., Savion-Lemieux, T. & Penhune, V. (2007). The effect of early musical training on adult motor performance: evidence for a sensitive period in motor learning. *Exp Brain Res, 176*, 332-340.

Waters, A. J., Townsend, E. & Underwood, G. . (1998). Expertise in musical sight reading: a study of pianists. *Br J Psychol, 89*(1), 123–149.

Wolf, T. (1976). A cognitive model of musical sight-reading. *J Psycholinguist Res, 5*(2), 143-171.

Wong, Y. K. & Gauthier, I. (2009). A Multimodal Neural Network Recruited by Expertise with Musical Notation. *Journal of Cognitive Neuroscience, 22*(4), 695-713.

Wurtz, P., Mueri, R. & Wiesendanger, M. (2009). Sight-reading of violinists: eye movements anticipate the musical flow. *Exp Brain Res, 194*(3), 445-450. doi:10.1007/s00221-009-1719-3

Yang, S.-N. & McConkie, G. W. (2001). Eye movements during reading: a theory of saccade initiation times. *Vision Research, 41*, 3567–3585.

Appendix 1: The 9 pieces played once with and then once without the metronome.

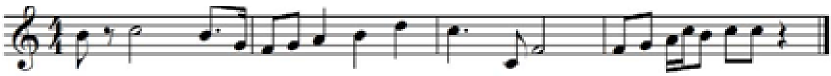

Image 1

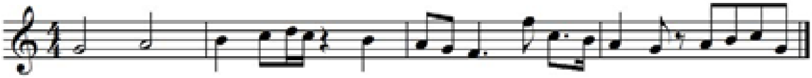

Image 2

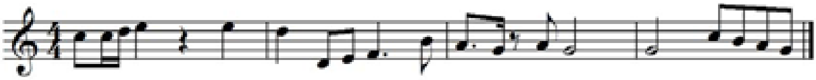

Image 3

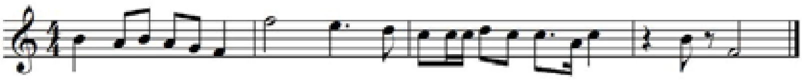

Image 4

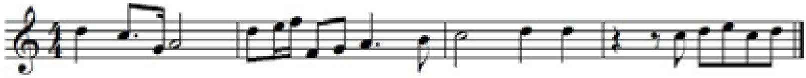

Image 5

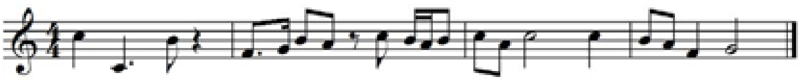

Image 6

Image 7

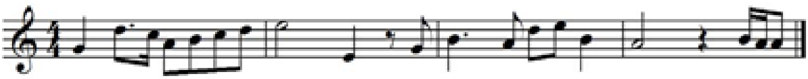

Image 8

Image 9