

Gaze behavior of a cellist: From sight-reading to performance

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Abstract

This study *used eye-tracking technology to investigate* the gaze behavior of an expert musician while learning a newly composed piece of contemporary classical cello music from the initial sight-reading of the score to a performance run-through. Unlike previous research relying on self-report and observation, this study combined analyses of physiological data and the musician's reported thought processes, offering a more comprehensive understanding of the learning-to-performance journey. The subject of investigation was the second movement (Introspection) of *Resonance* for solo cello by Jill Jarman. A combination of frame-by-frame and automated analysis of eye-tracking data allowed the capture of significant amounts of data across three data-collection points. Patterns of learning relating to technical challenges were displayed for this cellist across the recorded sessions, and initial links between self-reported thinking, cognitive processing, and the resulting recorded performance sessions were explored. Results provided preliminary insights into connections between perception, cognition, and performance, and advanced-level music learning approaches and performance practices.

Keywords

music, vision, pupillometry, search rate, music learning

Introduction

When reading words or music, the movement of the eye is non-linear, oscillating between *fixations* on specific areas to gather pertinent information and *saccades* (rapid shifts to the next relevant location) (Holmqvist et al., 2015). Eye-tracking technology facilitates the observation of eye movements and captures physiological characteristics related to visual processing, attention, and cognition. In the context of classical music, learning and performing often involve reading a musical score to grasp the intricacies of the composition, spanning basic note-reading to playing with nuanced expression. The process of learning to play a piece of music is iterative and entails spending dedicated time to the musical score and the instrument (Ericsson & Harwell, 2019). The eyes assimilate visual information to interpret the score, the mind engages in cognitive processing to comprehend the music, and physical action translates into musical expression through sound. By scrutinizing the patterns and locations of fixations, valuable

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insights can be gleaned concerning the musician's cognitive processes. This study aimed to employ eye-tracking technology to document the learning process as a musician progressed from sight-reading to mastering the piece in preparation for performance. By capturing and analyzing the eye movements, our objective was to offer preliminary insights into the intricate dynamics of music learning and performance.

(Sight)-reading words and music

The behavior of the eye when reading text adheres to established patterns of fixations for information gathering and saccades to the next fixation point (Rayner, 2009). Typically, individuals move their eyes in the expected forward direction while reading (e.g., left to right for English), yet approximately 10% to 15% of eye movements occur in the opposite direction, indicating efforts to identify errors or focus on areas that are hard to understand at first sight (Keating et al., 2014). The need to prolong fixations means that it takes longer to read unfamiliar material (Joseph et al., 2013). In the context of reading English, the eye has a *perceptual window* such that individuals typically process up to 15 characters to the right and up to four characters to the left of the fixation point (Liversedge et al., 2011). Distinct processes underlie the reading of notated music and written words, however. Playing music from the score has a "motor counterpart [that serves as a] verification of the reading process" (Puurtinen, 2018, p. 1), providing continuous physical and sonic evidence. The distinction between reading words and reading music highlights the multifaceted nature of music performance; interpreting and understanding the score involves integrating both physical and auditory elements. As musicians progress in learning and interpreting a piece, they rely increasingly on feedback from the ear to connect and reconcile their creative understanding with the physical sounds produced through the instrument (Luciani et al., 2024).

Reading an unfamiliar score and playing it at sight is called *sight-reading* and represents an advanced performance skill because the musician must transform the notated score into sound in real time, without having spent any (or much) time studying it in advance (Puurtinen, 2018). Effective sight-reading requires the musician to be able to perceive groupings and patterns in the notation and produce the sounds they represent on the instrument they are playing (Thompson & Lehmann, 2004). This skill is necessary for orchestral and chamber music, recording sessions, and accompaniment and is routinely tested in examination settings (Lehmann & McArthur, 2002). In the same way that printed text cannot be read aloud fluently unless the reader recognizes words and understands their grammatical function, notated music cannot be sight-read effectively unless the musician recognizes notes and the way they are grouped into patterns that are meaningful in the musical genres with which the musician is familiar (such as chords, scales, and arpeggios). When presented with a new score in an unfamiliar genre, the musician is unlikely to be able to perform the music accurately at sight, since the note patterns may not be familiar groupings or shapes that are already established in their vocabulary. They must thus familiarize themselves with the music by *learning* it so as to be able to play it fluently.

Sight-reading and eye-tracking

In the domain of music performance, eye-tracking has been used extensively to examine eye movements while sight-reading (Drai-Zerbib et al., 2012; Imai-Matsumura & Mutou, 2021; Wurtz et al., 2009; Zhukov et al., 2019). Fixations serve as points of focus, encompassing a single note, a group of notes, or collection of other symbols located in the vicinity (Penttinen

et al., 2015). Arthur et al. (2016) reported fixations lasting 500–700 ms on average, although Huovinen et al. (2018) noted that fixations could be longer if the music was complex.

Puurtinen (2018) conducted a comprehensive review of research published between 1994 and 2017 on music reading and eye-tracking and noted considerable variability across studies. Participants included expert and/or novice musicians. Materials varied from complete scores to excerpts and music for pianists to play with one hand only. *Music reading* included studying the score first, then playing, as well as sight-reading. Performance data in studies by Gilman and Underwood (2003), Rosemann et al. (2016), and Hadley et al. (2018) were excluded if criteria for accuracy were not met (e.g., rhythm, pitch). Imai-Matsumura and Mutou (2021) studied sight-reading by measuring differences between pianists' *eye-hand span* (the distance on the page between the note they are looking at and the note they are playing).

There have been very few studies using eye-tracking technology in music research other than to investigate sight-reading. Vandemoortele et al. (2018) used it in an exploratory study of the gaze behavior of trio musicians, but there are no studies of music practice and learning using eye-tracking technology and a repeated-measures design.

Music practice and learning

Music practice involves a meticulous process of deconstructive analysis, repetition, and re-synthesis. How et al. (2022) conducted a systematic review of 296 research outputs on music practice (1928–2020). Novice and expert learners vary widely in the extent of their engagement with music and their practice behaviors (McPherson & Renwick, 2011), but it is widely agreed that expert-level performance requires thousands of hours of practice (Ericsson et al., 1993; Ericsson & Harwell, 2019). Musicians continue to practice throughout their lifetimes as they learn new music, maintain dexterity and muscle tone, and cultivate their personal musical expression (How et al., 2022). This dedication to practice is epitomized in a quote attributed to the renowned pianist Rubinstein, widely disseminated across music schools and conservatories: “If I do not practice for a day, I know it; if I miss two days my friends know it; and if I miss three days, the public knows it” (Blatzell, 1905, p. 488).

The domain of music learning has been well explored with a focus on beginners (e.g., Hallam & Bautista, 2018), encompassing analyses of practice habits and demonstrations of teaching techniques (McPherson et al., 2018). In addition, Burt-Perkins and Mills (2008) investigated the role of chamber music participation in the development of performance skills for students. Simulated performances have been employed to address issues related to managing performance anxiety and performing in real time and gain insights into the intricate processes underlying performance (e.g., Williamon et al., 2014). Music learning has also been researched through observing teacher-student interactions, as in the case study carried out by López-Íñiguez and Pozo (2016) of an expert cello teacher teaching a 7-year-old student. Ritchie and Kearney (2018) introduced specific instructional methods to do with self-regulation in an intervention study involving teaching adult-beginner instrumentalists. In an overview of the research that had been carried out to date, Woody (2001) highlighted experts' cognition- and memory-related skills that could be of benefit to learners, and other research similarly describes the components of expertise. According to theoretical literature and its applications to practice, metacognition is central to both learning and performance (Concina, 2019), although few researchers have explored high-level musical learning in detail. McPherson et al. (2019) analyzed conservatoire students' learning and presented a framework for microanalysis based on

aspects of self-regulation, focusing on the student's thoughts and feelings as well as behaviors associated with self-regulation.

A study by Lisboa et al. (2004) provides an example of research on aspects of music learning in which the first author, a professional cellist, was also the participant. She learned the Prelude from the sixth Bach suite from sight-reading (although, as a cornerstone of the cello repertoire, it would already been very familiar to the performer) to a trial performance. She provided a verbal commentary during her practice sessions, all of which were video recorded. Memorization-related behaviors were analyzed but not gaze. The initial study was subsequently expanded to analyze a series of 10 performances from memory of the same work given by the same cellist (Chaffin et al., 2010), revealing a pattern of learning focusing first on structure, then on technique, and finally expression (see also Chaffin & Logan, 2006). This pattern, typical for expert musicians, is highlighted by Brown et al. (2015) in their discussion of the maintenance of musical skills.

Cara (2023) used eye-tracking to measure the visual monitoring (glances at the keyboard) and eye-hand span of 22 pianists who played through Bartok's *Slovakian Boy's Dance* (54 bars) four times. They were given 2 min between each playthrough in which they were allowed to practice. Improvements in performance following the short practice sessions were found to be related to the complexity of the music.

Eye-tracking technology offers the opportunity to obtain "moment-by-moment insight into unfolding cognition" (Carter & Luke, 2020, p. 50). Although music learning has been studied extensively, no studies have been published to date in which the participant is an expert musician, the material is complex and novel to the participant, and their gaze behavior is tracked from sight-reading to performance.

Aims

The current exploratory study employed eye-tracking technology to investigate expert-level musical learning, tracing the gaze behavior of a professional cellist as she encountered a newly composed and unfamiliar piece of music. In this study, *gaze behavior* encompasses fixations (duration and number) and increase in pupil dilation from baseline (see Table 1). Our primary aims were to describe changes in gaze behavior from sight-reading to performance, analyze the relationship between gaze behavior and performance metrics at three time-points, explore shifts in cognitive focus from technical to expressive aspects, and investigate how visual-attention patterns reflect different stages of learning and assimilation of the musical score. Through our analysis of the eye-tracking data, complemented by performance metrics and a verbal commentary, we sought to offer preliminary insights into the cognitive and sensory underpinnings that contribute to expert musical learning and performance. In this study, we aimed to provide a foundation for future research on the intricate dynamics of musical skill acquisition and expertise.

Method

Study design

The study made use of the opportunity for a performer, composer, and specialist in eye-tracking technology working at the same university to collaborate on a study of the performer's learning processes. It used a single-case study methodology, following the guidelines outlined by Yin (2003).

Table 1. Overview of gaze behavior across the piece.

	Duration	No. of errors	No. of fixations	Fixation duration (ms)	Search rate	Peak pupil dilation [baseline]
T1	7:17	37	3,552	420,253	118.3145	3.98 [3.77]
T2	6:15	24	2,201	354,691	161.1499	3.60 [3.55]
T3	4:59	1	1,004	265,025	263.9691	3.87 [3.59]

Note: T1 = first playthrough (sight-reading); T3 = final playthrough (performance setting).

Participant

The participant served as a critical case study (Farrugia, 2019); she was chosen because of her professional background as a cellist. The decision to employ a single-case study design stemmed from the intention to conduct an initial exploration of the learning process. The participant was a professional-level classically trained female cellist aged 48. She had undergraduate and postgraduate degrees in music performance and over 25 years' experience of teaching and performing. While she was very familiar with musical learning and music teaching, she had no working knowledge of the functionality of eye-tracking technology at the time of data collection.

Although the participant is the first author of this article, her initial role was only that of the performer. She was not involved with the technical aspects of data collection and did not view the data before they were analyzed or while they were being analyzed. In this way, any potential bias or interference that might have arisen during the process of carrying out the research was mitigated, ensuring the credibility and objectivity of the data and results (e.g., Babchuk, 1962; Probst, 2016).

Materials

For the purposes of the study, the participant learned and performed a piece of contemporary classical music composed especially for her, which she was due to play in two public performances in the coming months. The music was the second movement (Introspection) of *Resonance*, for solo cello, by Jill Jarman. In this movement, the composer aimed to explore the sonic capabilities of the cello; she describes it as quite different from the first movement of the work. Because the music was new to the participant, she had no preconceptions as to its style or structure, as she would have with a piece of Classical or Romantic music. Both participant and composer gave consent for the participant's learning and performing of the piece to be investigated and documented.

Introspection is 144 bars long with a range from C2 to E5 and involves a variety of advanced string techniques such as playing pitches and chords both *arco* and *pizzicato*; using the wood of the bow (*con battuto*); bowing one string while simultaneously plucking moving notes with the left hand on another string; adhering to specific indications as to the speed and intensity of vibrato; and the extensive use of harmonics. The performer must attend to irregularly changing tempo indications throughout the work. The movement begins at a tempo of 60 bpm ("with a sense of stillness and space"). Subsequent sections use multiple tempi, are faster and dance-like with compound double versus triple rhythms, and include a *misterioso* free section. The second public performance was to be given from memory and accompanied by synchronous cymatic images presented on a large screen, depicting the patterns in sand created as the

frequency of each musical pitch resonates on a metal plate (for a full explanation of the cymatic images, see Ritchie, 2023).

Apparatus

We used a head-mounted Tobii Pro 2.0 mobile eye tracker equipped with four sensors operating at a frequency of 50 Hz to quantify gaze behavior, specifically the relative position of the pupil and corneal reflection. The eye tracker was controlled by Tobii Pro Glasses Controller software. It recorded point-of-gaze by analyzing binocular corneal reflection in relation to an integrated-view camera. The camera captured visual information at a resolution of 1920×1080 pixels, operating at 25 frames per second, and offering a field of view of 90 degrees. To ensure accurate measurements, both the horizontal and vertical system accuracy was calibrated with a precision of 0.5 degrees. The head-mounted eye tracker had an 82-degree horizontal field of view and a 52-degree vertical field of view. We used the Tobii Pro Lab Analyzer to analyze the data (fixations and pupil diameter).

Procedure

Talk-aloud protocol. The participant was invited to provide a spoken verbal commentary while she read and played the piece at sight using a talk-aloud protocol (Ericsson & Simon, 1993). She was instructed to “feel free to speak out loud as you play. This could include expressing anything you are thinking or feeling”. This was intended to provide evidence of her awareness and visual, physical, and aural understanding of the music.

Data collection. Data collection took place in a university lecture hall, chosen for its controlled lighting conditions, ensuring consistency for the eye-tracking glasses. The participant, positioned with her cello in front of a music stand, underwent the calibration process for the eye-tracking glasses described above before the other researcher (the second author) revealed the sheet music to her for the first time. She was instructed to look at the music for approximately 1 min to familiarize herself with the score. She was then asked to play the music from beginning to end while also following the talk-aloud protocol instructions. To track the learning process over time, the same procedure was used in two subsequent data-collection sessions 3 and 6 weeks later. The composer was present during the third session to hear the participant play the piece to her for the first time, a typical scenario prior to public performances when a composer has written a piece for a performer. The participant practiced introspection every day for 30–90 min between the three data-collection sessions. In the third session, she played the piece to near-perfection, reporting just one error. In line with Fletcher (2019, 2024), no further data were collected.

Data processing. The data collected by the mobile eye tracker to measure gaze behavior and cognitive effort consisted of fixations and changes in pupil dilation, respectively. A fixation was defined as a sustained gaze maintained within 1 degree of visual angle for a minimum duration of 120 ms, as established by Vickers (1996) and Vickers and Williams (2007). For the purposes of analysis, we calculated mean numbers and durations of fixations observed across all trials (Nibbeling et al., 2012; Sharpe & Smith, 2024) and search rate by dividing the total number of fixations by the total duration of fixations (Moore et al., 2019). Pupil dilation was measured as follows: pupil size (right eye) was recorded first during the calibration process to obtain a baseline measure of mean pupil diameter and then recorded in situ peak pupil diameter at a refresh

rate of 30 Hz (see Campbell et al., 2019). Changes in pupil dilation were calculated by computing the difference between the in situ and baseline measure. In line with previous investigations (Kahya et al., 2018; Runswick et al., 2021; Sharpe et al., 2024), the dilation of the pupil of the right eye was used in all subsequent analyses.

To process the data collected, the second author identified Areas of Interest (AOI) for each section in the piece of music by mapping the eye-tracking video footage, which shows the moving gaze of the performer, onto a full static image of the sheet music, frame by frame. This was used to produce a heat map showing the locations in the score on which the participant fixated most often and for the longest (shown in red) in each of the three playthroughs. The second author also transcribed the audio recordings of the participant's verbal commentaries, which ranged from single words to complete sentences, as well as audible gasps and grunts that often signaled errors in the participant's playing.

Data analyses. In addition to fixations and pupil dilation, we analyzed errors in the participant's performance as indicated in her verbal commentaries. We illustrate her gaze behavior in a heat map and report descriptive statistics only, as we carried out a single-case observational study rather than an experiment.

Results

Performance and gaze behavior

The length of each playthrough decreased from 7 min 17 s at T1 (sight-reading) to 6 min 15 s at T2 and 4 min 59 s at T3 (first performance to composer). The number of errors indicated in the verbal commentaries also decreased from 37 at T1 to 1 at T3. As shown by the eye-tracking data, search rate increased from T1 to T3. The pattern of pupillometry data was relatively stable across the three playthroughs, indicating consistent cognitive effort or load. In the T1 playthrough, pupil dilation increased from the baseline in the opening section of the piece. It peaked in Bar 10, where a four-note chord is located requiring the participant to identify possible alternative fingerings, as evidenced by her spoken commentary:

This is a problem, because I would have played [plays cello] but then I can't play that one [plays cello], so I have to go up here [plays cello] and awkwardly I have to go [plays cello] and move that finger over. I wonder if there's a way around it?

In both the T2 and T3 playthroughs, peak pupil dilation was observed in Bar 26 (see Table 1).

Eye movements

The participant's eyes moved consistently from left to right except once in the T1 playthrough when she overlooked an instruction in the score when her eyes moved from right to left. She often looked ahead, particularly when approaching Bars 94–96 and playing Bars 108–109. To calculate changes in the numbers and durations of fixations on specific locations of the piece in each playthrough, we divided the piece into six sections (S1–6), based on tempo indications and instructions such as “gently” (see Table 2). Each of the sections received fewer fixations with a shorter total duration over the three playthroughs, except S3, in which there was an increase from T1 to T2, although the most striking decreases were in the first and last sections. Total durations of fixations increased in S4 and S5, and there was a large increase in the total

Table 2. Gaze behavior by section.

	Section 1 (S1) Bars 1–14	S2, Bars 15–20	S3, Bars 21–36	S4, Bars 37–82	S5, Bars 83–129	S6, Bars 130–144
T1	1201 [155551] ^a , b.10 (middle)	532 [131223], b.16 (end)	408 [93771], b.26	431 [19103], b.68	491 [11018], b.122	489 [9587], b.136
T2	458 [51772], b.10 (end)	378 [148960], b.16 (end)	396 [110374] ^a , b.24	408 [22031], b.80	291 [13451], b.104	270 [8103], b.130
T3	127 [41819], b.1	233 [40321], b.20	308 [43292] ^a , b.24	180 [39926], b.37	89 [46375], b.85	67 [53292], b.131

^aThis section contains the peak pupil measurement from that data-collection session; (text) = most prominent fixation location.

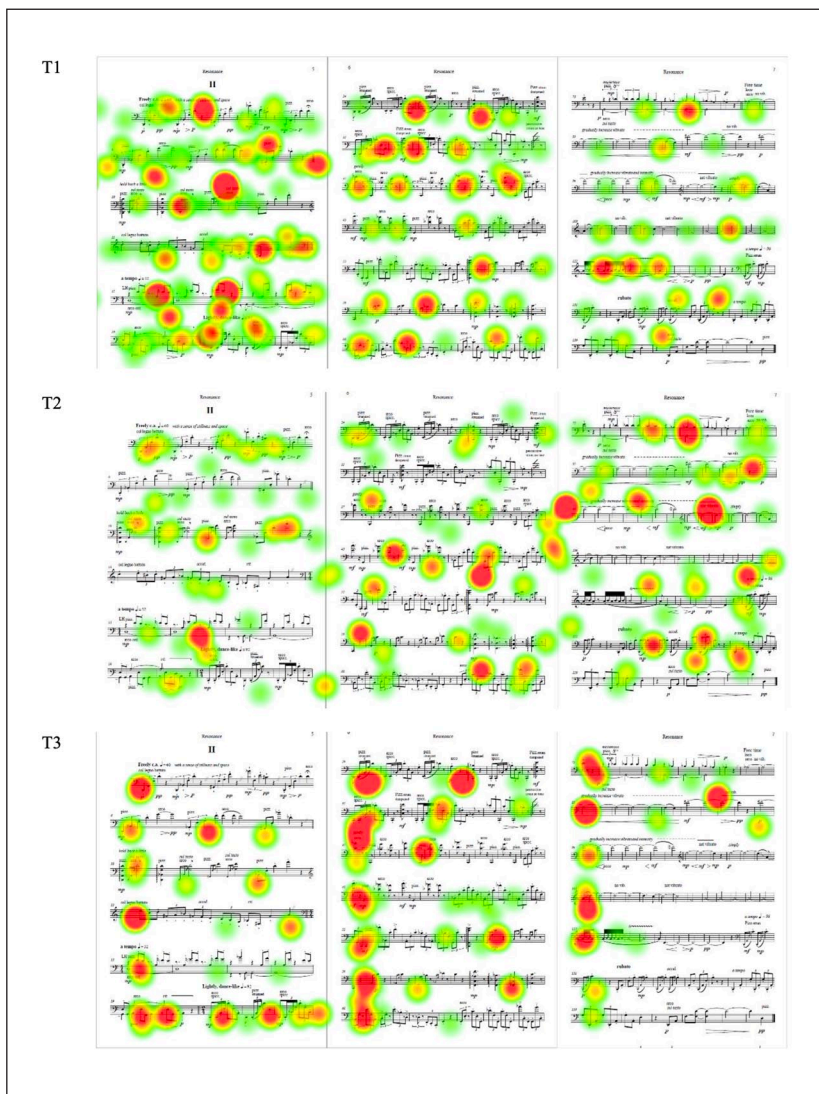


Figure 1. Visual representation of change-of-gaze across time-points mapped onto the musical score. Note: T1 = first playthrough (sight-reading); T3 = final playthrough (performance setting). A clean copy of the composer's score is available on request from the first author.

durations of fixations from T2 to T3. However, the duration of each playthrough became shorter as the participant gained proficiency in playing the piece.

Gaze behavior throughout the three playthroughs is illustrated in Figure 1. At T1, fixations were evenly distributed across the whole piece, but at T2, there were fewer, longer fixations, and at T3, it is clear that fixations were largely confined to the beginning of each line, other than at locations where the participant was making more cognitive effort, according to her verbal commentary.

At T1, her comments referred to technical errors, incorrect notes, or rhythms, such as “Just going through. I’ve messed up all the dynamics; that’s ok”; “I don’t know what that note is and

I have to read it in treble clef counting down C, B, A, G, F#"; "No C natural! Sorry." At T2 and T3, the commentary consisted to a greater extent of grunts and other sounds occurring at the locations of the composer's instructions on the score (e.g., dynamics, expressive directions).

Discussion

To contextualize our findings, this study examined how gaze behavior evolves across the learning stages from sight-reading to performance ready, the relationship between gaze patterns and performance metrics, and shifts in cognitive focus from technical to expressive aspects. By integrating eye-tracking data with performance metrics and verbal commentary, we aimed to illuminate the sensory and cognitive processes underlying expert musical learning and skill acquisition.

As the participant became more familiar with the piece, her playthroughs became shorter, and she made fewer errors. Her gaze behaviors changed, such that on the whole there were fewer but longer fixations. This finding aligns with previous research on visual search efficiency in skill acquisition (e.g., Runswick et al., 2021; Tien et al., 2014) and attentional control mechanisms in learning processes (e.g., Kulomäki et al., 2022; Young & Ellmers, 2022; Moore et al., 2019; Wilson et al., 2009). The stability of the pupillometry data across playthroughs could indicate consistent cognitive effort (Piquado et al., 2010; Porter et al., 2007) or cognitive load (Campbell et al., 2019; Moran, 2016) and may suggest the absence of state anxiety (Sirois & Brisson, 2014). The locations of peak pupil dilation highlighted areas of cognitive challenge, reflecting the participant's efforts to solve problems in technically demanding segments. Further analysis and investigation are warranted to deepen our understanding of the underlying mechanisms influencing these observations.

The fixation patterns in the three playthroughs align with the findings of previous research on expert music reading. For example, the concentration of fixations at the beginnings of lines in T3 may reflect the transition from reading, as such, to performing, as the participant assimilated the score and mastered the music (Imai-Matsumura & Mutou, 2021; Zhang et al., 2018). In T2, a significant decrease in the number of fixations across the duration of the piece was observed, indicating a more even and thorough reading of the musical score. This suggests that the participant was becoming more familiar with the music, but she still fixated intensely (i.e., for more time) on sections she had not yet mastered. For example, S5 includes long notes that must be sustained for up to eight bars. In T2 a distinct pattern of new fixations was observable in Bars 92–95, as she employed additional cognitive effort (see pupillometry data in Table 2) to give an expressive performance as indicated in the score (see Figure 2). After the T2 playthrough, she commented "I think that there will be a lot of thought required to do these long simple notes correctly."

A similar pattern of fixations was observed in T3, although she fixated even more intensely, as shown by the size and color on the heatmap (see Figure 1). The pattern of fixations on single notes in T1, technically challenging sections in T2 and again, although to a lesser extent, in T3 support the findings of Chaffin et al. (2010), which suggest that performers' initial focus on structural and technical aspects is replaced by focus on interpretative and expressive elements. Specifically, the sections on which the participant fixated intensely in T2 included Bars 46–50, Bar 69, and Bars 79–81 (see Figures 3 to 5). She fixated on them again in T3 but for less time and barely fixated on individual notes as she had done in T1.

Again, similar patterns of fixations were observed in T2 and T3 in Bars 13–14, such that there were fewer fixations in T3 but longer fixations at the beginning of Bar 13. This is not

intense vibrato decreasing to no vib.

91 92 93 94 95

mf *pp* *p*

Figure 2. Bars 92–95, representing an expressive, as opposed to a technical challenge.

45 46 47 48 49 50

mf *mp* *mf* *mp*

Figure 3. Bars 46–50, representing a technically challenging passage involving position work and quickly changing between using the bow and pizzicato.

68 69 70

mf *mp*

Figure 4. Bars 68–70 to show Bar 69 in context. Here the technical challenge involves a change of position and hand shape.

attributable to the technical challenge presented at this location. In earlier playthroughs, verbal commentary tended to coincide with technically challenging material, and in T3, there were no associated comments at this fixation point. When the participant played the piece through to the composer in T3, she fixated almost exclusively on the beginning of each line, suggesting that she was using the score as a prompt rather than reading it thoroughly. Furthermore, the changes observed in the talk-aloud protocol further support the idea of a progression from technical mastery to expressive interpretation. This shift demonstrates the performer's growing reliance on auditory feedback and creative conception of the piece as learning progressed, aligning with Holmes' assertion that "dynamic manipulation of sound is critical in performance" (Holmes, 2012, p. 302).

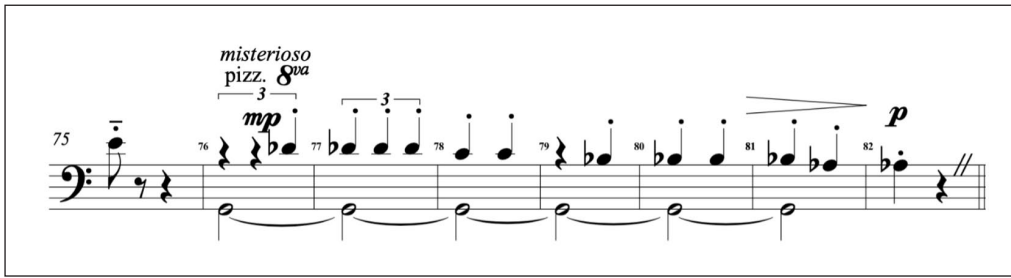


Figure 5. Bars 75–82, to contextualize the challenge of Bars 79–81, where one string is bowed while the left hand is simultaneously used to depress and pluck another string, using multiple fingers on the left hand, independently of the string being bowed.

The patterns of fixations in T3, illustrated in Figure 1, may indicate that the participant was in a state of *flow* (Csikszentmihalyi, 1975), which combines *deep concentration, action and awareness merging, becoming one with the activity, feeling in control, and forgetting oneself* (Beard, 2015). Flow is well documented in music (see Tan & Sin, 2021) and is associated both with expertise and with a decrease in cognitive control (Dietrich, 2004). Perhaps the fixations at the beginning of each line in T3 served as cognitive anchors or placeholders, as an orator at a graduation ceremony, their finger following the beginning of a list of names, keeps their place in their script while speaking mostly from memory. This speculation is supported by recent research linking high-flow neural activity in expert musicians with the specific regions of the brain that control auditory and sensorimotor activity (Rosen et al., 2024, p. 8).

A strength of the present study is the use of the verbal commentary to interpret the eye-tracking data. One limitation of the study, however, is that the decrease in the number and length of fixations from T1 to T2 and T3 cannot necessarily be attributed to changes in attentional focus, as argued above, because the playthroughs also became shorter. Another limitation is that we cannot say if the fixations in T3 at the beginning of each line of the score interrupted or enhanced the participant's sense of flow. We would nevertheless argue that Figure 1 illustrates the process whereby learning begins with sight-reading and progresses through a stage in which the performer gains understanding, expends less cognitive effort on reading as they rely on auditory feedback to confirm that they are matching their conception of the piece in their performance, and ultimately demonstrates their mastery of the piece, having largely memorized it.

Future directions. There is still a gap in the research on the dynamics of skill acquisition and development in music for in-depth investigations that track and analyze changes in patterns of eye movements over extended periods of time. Studies should not only involve multiple rather than single data-collection sessions but also investigate the gaze behavior of musicians of different levels of expertise learning music in real-world practice situations rather than the laboratory. The findings of such studies would enhance our understanding of the intricate physical and mental mechanisms underlying musical expertise. The present case study was opportunistic and designed to be exploratory. Future research with a larger sample of musicians learning the same piece in controlled conditions could help explain the cognitive processes underlying the development of musical expertise.

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Ethical considerations

Ethical approval for the study protocol was awarded by the University of Chichester Research Ethics Committee (Approval Number 2122_41).

Author contributions

L.R. gained ethical approval for the project. L.R. performed cello as the participant. B.T.S. collected and analyzed data. L.R. prepared the first draft of the manuscript. Both authors edited the manuscript and approved the final version.

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Transparency and openness statement

The data set for this research can be found on the Open Science Framework (see <https://osf.io/8q5w4/> overview).

Data availability statement

Anonymized data can be made available upon reasonable request.

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