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Looking into the eyes of a conductor performing Lerdahl's "Time after Time"

E. BIGAND*, P. LALITTE*, F. LERDAHL**, J-M BOUCHEIX*,
Y GÉRARD* & T. POZZO***
** Laboratoire d'Etude de l'Apprentissage et du Développement,
UMR CNRS 5022, Université de Bourgogne, France*
*** Music Department, Columbia University, NewYork USA,*
*** U887 *Motricté-Plasticité INSERM, Université de Bourgogne, France*

• **ABSTRACT**

The eye movements of a conductor were tracked during a performance of Lerdahl's "Time after time". The analysis of the data revealed that, for most of the time, the conductor was looking at the score, rather than the performers. Most of the score-reading was in anticipation of the music to be played. Micro- and macro-anticipations could be defined, the former being between 2 to 5 seconds in advance, the later being more than 5 seconds in advance. The largest visual anticipations were as long as 10 seconds. The longer anticipations were found to correspond to the occurrence of those thematic cells the conductor considered to be of expressive importance for the piece. This suggests that the conductor's eye movements were governed on a small scale by the coordination of instrumental performance and on the large scale by his musical conception of the piece.

Eye tracking is the process of measuring either the point of gaze or the motion of the eye relative to the head. Eye movements consist of a series of eye fixations and saccades between fixations. They can thus be characterized by the two indicators: fixations, when the eye gaze pauses in a certain position; and saccades, when it moves to another position. Together, the indicators express how a subject performs in a given task. Generally, the longer the eye fixation, the deeper the cognitive processes involved in the studied activity (Baccino, 2004; Baccino & Colombi, 2001; Goldberg & Kotval, 1999; Goldberg & Schryver, 1995; Holmqvist *et al.*, 2003; Rayner, 1998). Eye saccades further indicate when the subject processes specific information. In activities such as text or music reading, forward saccades occur when subjects look forward to the forthcoming information. Backward saccades intervene when subjects check past information - in complex sentences, for example.

A wide variety of disciplines use eye tracking techniques, including cognitive sciences, psycholinguistics, visual perception, human-computer interaction, computer usability, cognitive ergonomics, sport training, market research (advertising), medical research, and communication systems for the disabled. In the field of web usability, eye tracking provides insight into which features are the most eye-catching, which features cause confusion and which ones are ignored altogether. In automotive design, research is currently under way to integrate eye-tracking cameras into automobiles. If the eye behavior of the driver can be monitored in real time, driving safety could be dramatically enhanced. In medicine, Grant and Spivey (2003) used an eye tracking method to study complex problem-solving such as curing a skin cancer with laser techniques without damaging proximal zones of the skin. In X-ray recognition by radiologists, Myles-Worsley, Johnston, and Simons (1988) showed how eye tracking could reveal chunking activities or relevant visual patterns in medical experts. Eye tracking has been used recently also in multimedia learning research (Boucheix & Lowe, in press; Hyönä, in press; Mayer, in press) and in communication systems for disabled allowing the user to speak, mail, surf the web, and so on, with only the eyes as a tool.

In cognitive psychology, eye movements have been used mainly in analyzing reading activity, visual search of information (websites, for example) and scene perception. Research is more complete in reading than in visual search or scene perception (Castelhano & Rayner, 2008; Hyönä, Radach & Deubel, 2003; Rayner, 1998). Reading a text is a well-defined task for the viewer: understand a text. Reading involves a sequence of eye movements, typically from left to right across a page and down the page. In more physical working activities, the task and the goals of the worker are generally well defined and susceptible to task analysis. Such is notably the case for car or truck driving (Shinar, 2008), medical diagnosis (Grant & Spivey, 2003; Myles-Worsley *et al.*, 1988), and air traffic control (Mandran *et al.*, 2007).

Since the 1970s, eye-tracking methods expanded rapidly in the research of reading. Eye movement norms and basic characteristics have been established as shown in Table 1.

Table 1.

Eye movement characteristics in reading, scene perception and visual search, inspired from Baccino, 2004 and Castelhano & Rayner, 2008.

Task	Mean fixation Duration (ms)	Mean saccade size (degrees)
Silent Reading	225-250	2 (7-9 letter space)
Oral reading	275-325	1.5 (6-7 letter space)
Scene perception	260-350	4
Visual search	180-275	3
Score reading	375	1

Eye movements in reading text have been claimed to be similar to those in reading music (Rayner, 1998). The interdependency of reading ability in text and music remains however a matter of debate, with some studies supporting similar processes (Hébert *et al.* 2008; Roux *et al.*, 2007), and others favouring some dissimilarity. For example, Sergent *et al.* (1992) found that text and music reading involved adjacent but distinct neural networks. One cause of the difference between text and score reading could be the strict and continual time constraint of musical performance. The reading of language aloud, which, like musical performance, involves turning coded information into a musculoskeletal response, is comparatively free of temporal constraint, which is not the case in most of western music. As a consequence, music reading is an extremely demanding skill that remains difficult even for highly trained musicians.

Given the complexity of music reading, most of the studies using eye tracking in music have dealt with sight-reading in pianists, and, to a lesser extent, violinists. Not surprisingly, research has aimed primarily at comparing the eye movement patterns of skilled and unskilled performers (see Madell & Hébert, 2008, for a review). Expert sight-readers used shorter eye fixations, spending between 200 and 400 ms, some 100 ms shorter than those of the non-experts. Expert sight-readers are also able to anticipate larger sizes of musical information (Furneaux & Land, 1999), and have a larger eye-hand span (Truitt *et al.*, 1997; Gilman & Underwood, 2003). The eye-hand span defines the distance between what the eyes are looking for in the score and what the hand is playing (usually the right hand in pianists). This distance between perception and performance may be expressed in time or in amount of information. Truitt *et al.* (1997) and Gilman & Underwood (2003) reported that the eye-hand span is about two quarter notes in experts, and less than one beat for less expert musicians. The time lag between perception and performance also depends upon tempo, and varies in pianists from 07 to 1.3s for fast and slow tempi, respectively. Surprisingly, several studies reported that pianists spend a large amount of time looking away from the keyboard (49% of the length of the note according to Truitt *et al.* (1997), 57.5% according to Gilman and Underwood (2003).

In addition to expertise, musical complexity (in score or in structure) also influences eye movements. At least three types of complexity need to be accounted for in music reading: the visual complexity of the musical notation; the complexity of processing visual input into musculoskeletal commands; and the complexity of executing those commands. For example, visual complexity might arise from the density of the notational symbols on the page, or from the presence of accidentals, triplet signs, slurs or other expression markings. The complexity of processing visual input into musculoskeletal commands might involve a lack of "chunkability" or predictability in the music. The complexity of executing musculoskeletal commands might be seen in terms of the demands of fingering and hand position. Lesser complexity yields shorter saccades (Jacobson, 1928; Polanka, 1995; Weaver, 1943) In addition, the musical structure also influences eye-hand span: Sloboda (1974, 1977) found that expert pianists extend eye-spans toward phrase endings.

A few studies focused on sight-reading in performers other than pianists. In a recent study (Wurtz, Mueri, & Wiesendanger, 2009), a group of violinists was required to sight-read Telemann and Corelli scores, the former score being more complex to sight-read. Eye and bow movements were recorded, allowing the study to relate perception to performance. Mean fixations (*i.e.*, when the eye gaze pauses in a certain position) were shorter (349 ms versus 417 ms), and there were less backward saccades (*i.e.*, when the eyes move towards information already seen) for the less complex scores. The perception-performance span was modulated by the tempo chosen for playing the score, with smaller spans for faster tempi. However, the number of notes anticipated on the score was not affected by the tempo. More notes were anticipated in the simpler scores (*i.e.*, 6 versus 3.3 notes), and the violinists were, for both pieces, one second in advance on average over the group, with one violinist being 1.89 seconds in advance. This study's findings are consistent with those reported with pianists: musical complexity results in longer fixations, numerous regressive fixations, and reduction of the amount of information anticipated.

Kinsler and Carpenter's (1995) model integrates these data. According to this model, three basic computational units govern music reading: (1) a general-purpose encoder, which extracts the visual stimulus; (2) a music-specific processor, which extracts the musical meaning from the signal; and (3) an executive unit that sends information to the motor system. Units 2 and 3 connect by a buffer that correlates the loading of incoming information with the muscular programme. Expert sight-readers are likely to have a more efficient buffer as well as a more efficient ability to extract musical meaning from a score. The size of this buffer is imagined to determine the amplitude and the timing of eye movements. Music performers have two tasks to perform simultaneously: loading and analyzing incoming musical information in working memory, while programming the motor action to act on this information. Expert sight-readers are those who manage to reduce the attentional cost of both tasks. The reduction of attentional cost is likely to be achieved by the development of routines to read and identify relevant musical structure, and the development of automatic motor skills to perform familiar patterns of western music.

To our knowledge, eye movements of conductors have never been investigated, and eye tracking has always been addressed only with western tonal music. Both points raise interesting issues for music cognition. The cognitive processes involved in conducting music remain largely unstudied, despite the considerable complexity of the mental processes involved. Conductors have to coordinate a large amount of information related to quite specific details of musical performance, while keeping in mind the large-scale structure of the piece. At the same time, they constantly adjust their intended idealized performance, depending upon the actual performance of the orchestra. According to the usual ergonomic classification of tasks, the conductor's activity belongs to the same category as driving and supervising a dynamic environment (Cellier, Eyrolle, & Mariné, 1997; Farrington-Darbi & Wilson, 2006; Glaser and Chi, 1988; Shanteau, 1992). In the literature, dynamic environments are defined according to several criteria. The first is the complexity of the task. The second is the indirect access to the whole working field, and thus the building of a complete and consistent mental model of the development of the situation. Another criterion relates to the changing, over time, of parametric values. Conducting a musical ensemble is a dynamic multi-task activity, which involves reading a score with multiple instruments, scene perception, motor execution, temporal supervision (with implicit or explicit instructions to musicians relative to the score), and interpretation of music during a playing session. Because the music supervision changes quickly during the performance, and because the conductor has a limited control over the whole situation, directing a performance requires anticipation and representation of the probable states (or difficulties) to come. This anticipation process, in a dynamic environment, is a crucial feature of the task. Accordingly we anticipated that eye tracking fixations and saccades would express the cognitive anticipation of the conductor.

Conducting an ensemble is most demanding in the case of a musical language of novelty and difficulty, as in some contemporary music. For this new style of music, executive routines are less developed than for classical music, and the problem of the overall structure of pieces is more pronounced. This is notably the case for the first performance of a piece. The purpose of the present study was to provide a preliminary account of the eye movements of a conductor during the rehearsal of a contemporary piece, Fred Lerdahl's *Time after Time* (2000), in its first performance in France. The purpose was not to investigate how conductors sight-read a contemporary score. The focus was to infer from eye movements the cognitive processes and strategies used while conducting the piece.

The greatest point of interest was to investigate how the conductor deals with reading anticipation and eye fixations on specific thematic materials, and how eye movements express his own musical understanding of the piece. We hypothesized that the particular form of the piece, the variable complexity of the thematic material and the technical task of conducting the performers influence the strategies of the conductor.

Lerdahl's *Time after Time* exhibits several interesting characteristics for this purpose. It is a piece for chamber ensemble of 6 instruments (piano, percussion, violin, cello, clarinet and flute) composed in 2000 for the Washington Square Contemporary Music Society (New York) and Collage (Boston). The Washington Square group gave the premiere in 2000 in New York City, conducted by Paul Hostetter. The piece is in two movements, about 8 and 11 minutes long respectively. The present study focuses on the first movement, composed in a spiral-like musical form. A short musical idea (theme A), characterized at the beginning of the piece by trills, becomes longer and more complex with each of the 14 turns of the spiral. If one takes the eighth as the temporal unit (the tempo does not change), the turns expand from 3 to 385 notes (about 1 second to 2 minutes). The recurrences of the theme are in bars 1 – 2 – 3 – 4 – 6 – 9 – 13 – 19 – 29 – 41 – 59 – 88 – 126 – 175.

The boundaries between these sections become increasingly blurred in the course of the movement because of overlapping contrapuntal strands. As the main theme expands, new ideas emerge out of it. Three secondary themes come in between each new turn of the spiral (see Figure 1). Theme B is a brilliant and complex texture made of chords (piano, vibraphone and glockenspiel) and arpeggios (woodwinds and strings). It occurs 8 times (bars 14 – 21 – 31 – 45 – 64 – 95 – 137 – 191). Theme C is a soft and melodic texture coloured by clarinet and strings. It occurs 7 times (bars 25 – 36 – 53 – 76 – 110 – 155 – 213). The coda-like Theme D is an octatonic low flute line in steady 16th notes, which becomes prominent toward the end of the movement. It occurs 3 times (bars 120 - 166 – 229). As illustrated in Figure 1, the spiral-like form is schematized by 14 ellipses each of them representing the temporal expansion of the theme A. The occurrences of the secondary themes are placed on the ellipses and are symbolized by a triangle (theme B), a square (theme C), and a circle (theme D).

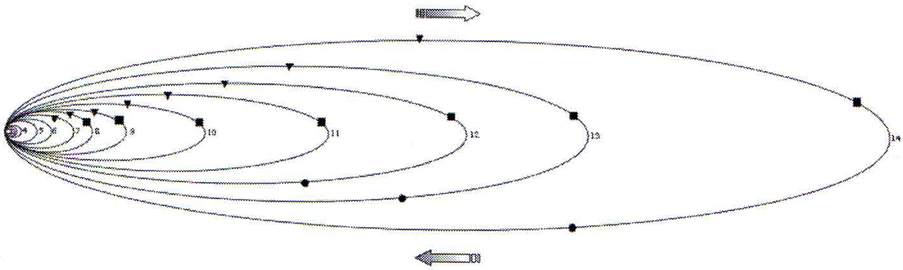

Figure 1.

Figure 1. The spiral-like form is schematized by 14 ellipses each of them representing the temporal expansion of the theme A. The occurrences of the secondary themes are placed on the ellipses and are symbolized by a triangle (theme B), a square (theme C), and a circle (theme D). The arrows show the direction of the ellipse in time.

Experimental method

The experiment was run in January 2008, during a workshop that celebrated the 25th birthday of Lerdahl and Jackendoff's (1983) *A Generative Theory of Tonal Music* (see Bigand, Lalitte, & Dowling, 2009). Lerdahl's *Time after Time* was performed in France for this occasion by a professional ensemble specializing in contemporary music, Ensemble XXI, conducted by Dominique Dournaud. The eye movements and body motions of the conductor were captured during the third rehearsal (see Figure 2). Given that there had been two rehearsals already, both conductor and performers had solved most of the technical difficulties of the score, and they focused on expressive interpretation during the monitored rehearsal. This session was done in the presence of the composer, who gave feedback to the conductor during rehearsal intermissions, but not while the piece was actually being rehearsed. The piece was first played through segment by segment (each usually less than 2 minutes). When the ensemble reached the end of the first movement, the conductor decided to play the entire movement without pause. We focus here on the analysis of the eye movements during this complete performance.

Figure 2.

Eye tracking the conductor performing Lerdahl's Time after Time, at Université de Bourgogne, France.

Procedure

Eye movements were recorded with a 50 Hz ASL corneal reflectance and pupil centre Mobile Eye Tracker (figure 2, top). This system utilizes an eyeglass-mounted eye tracker. The glasses are very light to wear and equipped with two special cameras. One camera records the scene in front of the conductor and the other records eye gazes. The two cameras were synchronized (interwoven systems). This mobile system allows real-life eye recording, even with the head moving, and was perfectly adapted to our research needs. Data were recorded with OCS software specially designed for videotaped eye gazes. The score was positioned approximately 80 centimeters in front of the conductor. The video recording of the eye mobile eye tracking system was equipped with a sound recorder synchronized with the eye recording. In addition, the music was also recorded with high-quality sound equipment, producing a multimedia video of high standard.

Data analysis

In order to analyze the conductor's eye movements, we defined Areas of Interest (AOI) that correspond to the two lines of music staves present in each page of the score (Figure 3). Each line uses eight staves vertically arranged – one for each of the flute, clarinet, viola and 'cello, and two each for the percussion and the piano. Given there were 33 pages in the score of the first movement, there were 66 AOI to analyze, all of the same size.

In analysing the data, we distinguished three categories of score reading: Score Following, Micro-Advance, and Macro-Advance. Score Following is the temporal matching of score reading and music flow. A Macro-Advance is a fixation appearing always in the next line and of 5 to 10 seconds in length. A Micro-Advance is between 2 and 5 seconds, with fixation generally inside the current line, up to 5 seconds, and sometimes in the next line, beyond 2 seconds. We processed eye fixation durations in each AOI and the location of these fixations in performance time. We hypothesize that fixation durations provide information about the conductor's depth of cognitive processing: the longer the fixation, the deeper the processing. Within each AOI, that is, each stave, the scan path showed the trajectory of the eye between groups of notes as well as between performers. Figure 3 shows the distribution of eye-fixation durations within a single line. It also shows that these fixations can occur within a line following that from which the actual music is being played (left part of the Figure 3).

This AOI (Figure 3) is one of those that, in total, amount to the longest eye fixation in the first movement (about 8 seconds). Inside this AOI, we can see the scan path of the conductor. The scan path shows five specific locations of long fixations, each containing a series of fixations (shown by doted ellipses numbered from 1 to 5). The first and the second eye fixations, lasting respectively 320 and 160 ms, focused on chords played by the strings. The third and the fourth fixations lasted longer, respectively 1200 and 1400 ms, and focused on the melody played by the

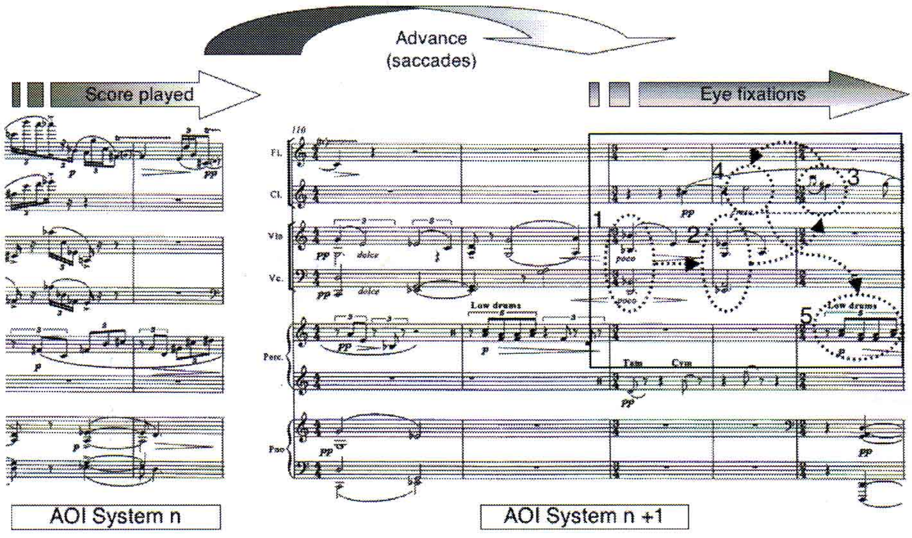

Figure 3.

Each line contains 8 parts. The lines define Areas Of Interest (AOI) for analyzing eye movements. This example shows the scan path of fixations within an AOI, in this case in five different locations. These fixations occurred in advance of the score being played. This played score is related to a previous line (part of line presented on the picture).

clarinetist. The last fixation of this AOI lasted 560 ms, and focused on the low drum part. All these fixations are Micro Advances. After that, the conductor returned to the score-following strategy, looking at the beginning of the same line. In some cases, there were regressions over the scan path, returning to an earlier part of the score.

A first analysis revealed that there were more eye fixations on the score (Figure 4, top) than on the performers (Figure 4, bottom). When looking at the ensemble, the conductor spent more time looking at the clarinetist and the flutist. This finding may reflect either the influence of the spatial organization of the ensemble (the flutist and clarinetist were in front of the conductor), or the relevance of a particular thematic cell these two performers regularly play. The rest of the analysis was devoted to the eye movements on the score. The analysis was focused on two relevant aspects of the eye fixations: their duration and their advance as the music unfolded. These indicators, distribution of fixations on the lines coupled with their time advance, provide a good representation of eye movement across the lines during the performance. Furthermore, given that fixation duration and fixation number are usually highly correlated, (*i.e.*, the duration of fixation decreases when the number of fixations increase; see Baccino & Colombi, 2001; Castelhano & Rayner, 2008; Hyönä *et al.*, 2003; Rayner, 1998), only fixation duration data are reported in the present paper.

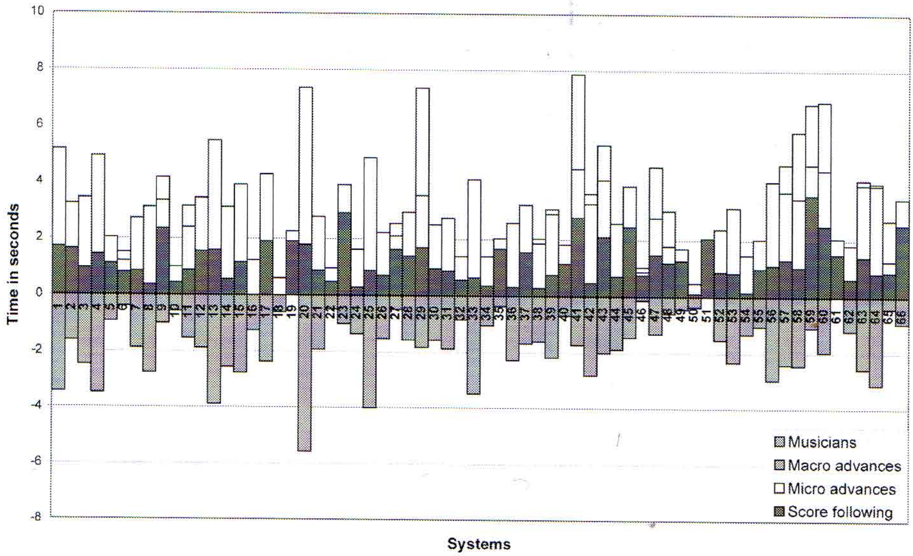

Figure 4.

Mean fixation durations per AOI, recorded during the performing of the first movement of Lerdahl's Time after Time, with eye fixation toward the score (top) and the performers (bottom). Two categories of advance were distinguished: Micro-Advances, Macro-Advances. Other fixations referred to as Score Following in Figure 4 are almost synchronized with the music performance.

Table 2 shows mean duration of fixation per AOI, relative to figure 4. The longest fixations were observed for Micro Advance, and the shortest were observed for Macro Advance.

Table 2.
Durations of fixation per AOI.

	Score Following	Micro-Advance	Macro-Advance
Mean (ms)	1235	1754	1142
Maximum (ms)	3600	5560	3800
Minimum (ms)	120	120	80
No. of lines	64	63	22

However, as shown in Table 3, the duration of fixations on specific locations within a line (see Figure 3) indicates that fixation durations for both Micro- and Macro-Advances were longer than those of fixation on Score Following. The number of specific locations of fixation within an AOI was inversely proportional to the advance (Table 4). This means that in Macro Advances the number of locations focussed on was lower than that in Micro Advances, and in Micro Advances the number of locations focussed on was lower than in Score Following. Perhaps in order to manage limited cognitive resources, the conductor tended to process less information in Macro-Advances.

Table 3.
Durations of fixation on specific locations within a line.

	Score Following	Micro-Advance	Macro-Advance
Mean (ms)	323	617	613
Maximum (ms)	1760	2600	2940
Minimum (ms)	40	40	80

Table 4.
Number of specific areas fixated per line.

	Score Following	Micro-Advance	Macro-Advance
Mean (freq)	3.83	2.84	1.86
Maximum (freq)	11	7	6
Minimum (freq)	1	1	1

Thus, for the three categories of advance (Table 5), we observed the conductor spending more time in Micro- and Macro-Advances (63.2 % of the reading time) than on Score Following (36.8 %). Micro-Advances represented the largest percentage of reading time: 51.5 % vs. 11.7 % for Micro-Advances. As illustrated in Table 5, Macro-Advances became more frequent (7 vs. 34) and longer (10.7 % vs. 89.3) from line 29 to line 66 (end of the movement). Because of the spiral-like form of the movement, the occurrences of themes became less frequent and less narrow. That should give the conductor more time to spend on anticipation. In other words, the density of themes decreased as a function of the expansion of the spiral-like form. This pattern of results was observed only in the case of Macro-Advances (see Table 5). The conductor spent only 10.7% of the total Macro-Advance time on lines 1 to 28. In addition, the mean duration of fixation in Macro-Advances between lines 1

Table 5.
Duration fixation (in sec) and percentage of time spent as a function of the size of the eye anticipation in time (Score Following, Micro- and Macro-Advances).

Duration	Score Following	Micro-Advance	Macro-Advance
Lines 1-28	32.28 (40.9 %)	53.2 (48.1 %)	2.68 (10.7 %)
Lines 29-66	46.74 (59.1 %)	57.32 (51.9 %)	22.44 (89.3 %)
Total (sec) (%)	79.02 36.8	110.52 51.5	25.12 11.7

to 28 was 383 ms, while the mean duration of fixation between line 29 and the end of the movement was 660 ms.

A critical issue was to assess whether the conductor's eye movements were related to the musical structure of the piece. As shown in Table 6, the eye fixation-durations varied greatly amongst the four thematic cells (here abbreviated to "themes"). Theme C had the highest fixation duration (40.56 sec), suggesting that the conductor gave more attention to that theme.

Table 6.

Eye fixation duration found for each of the four themes.

	Fixation duration (sec)	Number of occurrence
A	25,16	14
B	17,92	8
C	40,56	7
D	8,12	3

The importance of theme C to the interpretation of the music was confirmed by the analysis of the Micro- and Macro-Advances. The largest fixation duration (about 9 seconds) within a Micro-Advance (> 2 sec) occurred during theme C at line 29 (see Figure 3). The largest Macro-Advances (see Figure 4) occurred also during theme C (lines 6 - 9 – 13 – 20 - 29 – 41 – 58). That meant that the conductor changed strategy during the end of theme B to anticipate the next appearance of theme C. In other words, when the musicians played the end of theme B, the conductor left the Score Following strategy for a Macro-Advance strategy in order to load the forthcoming information into memory.

Further evidence of the interpretive importance of theme C came from the expressive tempo used by the conductor and the link between this expressive tempo and the duration of the eye fixations. As illustrated in Figure 5, there were interesting differences between the designated tempo and the tempo actually performed. The tempo is given in the score as ninety crotchet beats per minute, and we compared the theoretical duration of each line with that of the performance. The comparison analysis indicated how the conductor changed the tempo during the performance. The conductor slowed down the tempo only in specific lines, notably those containing theme C. This suggests that the conductor considered the occurrence of theme C as to be a strong expressive feature, the expressiveness being highlighted by slowing down the tempo. Quite interestingly, theme C is always played by the clarinet, that is, one of the performers whom the conductor looked at most often. Eye anticipations were also related to the occurrence of theme C. Figure 6 makes this correspondence clearer. The six peaks of eye anticipations (lines 9, 13, 20, 29, 41, 59), all correspond to the recurrence of theme C. The correlation between performance duration and fixation duration of each line reach significance (r (64) = .71, $p < .01$).

For themes A and B, the conductor had to keep metronomic accuracy because of the rhythmic intricacy of the score. Large anticipations might have confused the performers. As the conductor reached the end of theme B, however, he anticipated the more flexible cantabile character of theme C, which he conducted more slowly and flexibly. This flexibility required greater anticipation for the conductor, because players need signals in advance when the tempo varies. In contrast, the regular rhythms of theme D caused a subsequent return to relative strictness.

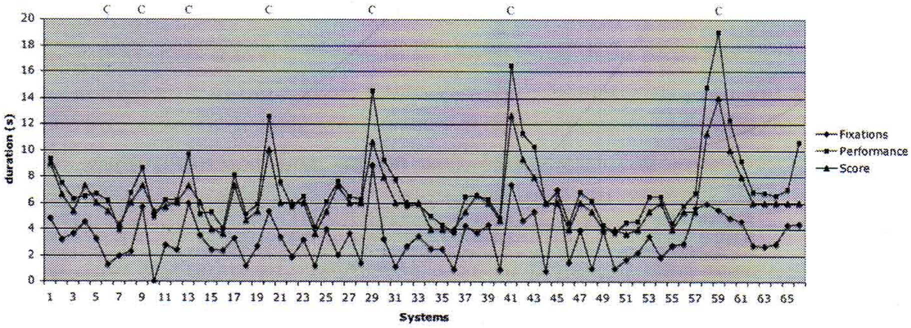

Figure 5.

Comparison of theoretical (Score) and performed (Performance) tempi, and eye mean fixation durations (Fixations); occurrences of theme C are indicated in the top of the figure.

Discussion

The present study investigated the eye movements of a conductor during the third rehearsal of the piece *Time after Time* by Fred Lerdahl. His eye movements were tracked throughout the performance of the first movement of the piece. The analysis showed that the conductor spent more time reading the score than looking at the musicians, and that most of the reading time was used to read musical information in advance of the sounding music. Micro-Advances (between 2 to 5 seconds) were the most frequent, and extended eye anticipations as far as 10 seconds were found. The durations of eye fixations depended on both the size of the advance and the thematic structure in the musical score. The first critical finding of the study is the large perception-performance spans (that is to say, the temporal difference between the eye gaze and the sounding of the music), much greater for the conductor than for pianists or violinists analyzed in previous studies (which is about 1 second). This difference should be considered with caution, since, in previous studies, the eye-hand spans of pianists and violinists were usually recorded when performers were sight-reading the score (Furneaux & Land, 1999; Galyen, 2005; Gilman and Underwood, 2003; Kopiez *et al.*, 2006; Lee, 2006; Lehman & Ericsson, 1993; Lehman &

McArthur, 2002, Lehman & Kopiez, 2009; Rayner & Pollatsek, 1997; Thompson & Lehman, 2004; Truitt, *et al.*, 1997; Waters, Townsend, & Underwood, 1998; Wurtz, Mueri, & Wiesendanger, 2009). It may be that pianists and violinists may have much larger eye-hand anticipations when they have had enough time to study and practice a piece. It is likely, however, that large-scale eye anticipations reflect specific cognitive activities in the conductor. The task of the conductor is a complex and multimodal dynamic multi-task activity, involving the reading of a score with multiple instruments, scene perception (the performing musicians), motor execution (movement of the baton), temporal supervision, and interpretation of music during a playing session. This task is quite different from the inter-modal activities of sight-reading usually studied in music using eye-tracking methods. Given that conductors do not have to load into working memory all the specific motor skills indispensable for a good musical performance, they may spend more time in anticipation of the music yet to come.

The present data further revealed that Micro- and Macro-Advances in eye movement were related to the form of the piece and the thematic material. Micro-Advances were numerous at the beginning of the piece, that is to say, when the thematic materials were presented in close proximity. The spiral-like form of the piece led to a progressive increase of the time between occurrences of the thematic cells, allowing the conductor more time to anticipate expressive features. These large-scale anticipations were related to expressive changes in tempo. This suggests that they contributed to tempo modulation. Although tempo modulation may be performed quite easily by a single performer, such changes are more difficult when performed by a large ensemble, and the conductor must convey them well in advance.

The present study does not address the factors that lead the conductor to move his eye from score to the performers. The conductor spent more time looking at the clarinetist who played theme C. This suggests that important musical themes are anticipated by the conductor, who then molds their execution by directly looking at the performers. Our results about anticipation from the score by the conductor are clearly in accord with data on dynamic tasks deriving from ergonomic studies, such as power-plant supervision (Hoc & Amalberti, 2005); air traffic control, aircraft pilots (Amalberti, 2001), bus traffic control (Mailles, Mariné, & Cellier, 1998) or in the medical emergency area (Bonnetain & Boucheix, in press). However, our research brings a new result in showing different levels of anticipation: Micro- and Macro-advances. This kind of "scale" of advance suggests the relative size of the "field of anticipation" of the conductor. An interesting hypothesis is that the size of the field of anticipation may be related to the expertise of the conductor, his prior knowledge of the score, and the difficulty and musical characteristics of the music. Another possibility could concern the subjective preferences of the conductor (aesthetical, emotional). This concept of field of anticipation could also relate to the concept of long-term working memory developed by Ericsson & Kintsch (1995).

The final contribution of the study is to highlight the musical interpretation the conductor had of the piece. The very contrasted thematic materials offer several cues, which facilitate the segmentation of the piece. According to the cue abstraction model by Deliège (1989), which is based on the principles of similarity and difference, these cues generate anticipation and understanding of the structure of the piece. Eye movements express the conductor's musical understanding of the piece. Notably, the conductor appeared to organize the performance by focusing on theme C, which is not the most structurally important nor the most climactic element of the piece, but the most contrasted material. The treatment of theme C by the present conductor was a notable feature of the performance.

Address for correspondence:
E. Bigand
LEAD CNRS UMR 5022
Université de Bourgogne
Pôle AAFE 2
Esplanade Erasme BP 26513
21065 Dijon Cedex
France
E-Mail: Bigand@u-bourgogne.fr

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