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Communications in Computer and Information Science 943

Language, Music and Computing

Second International Workshop, LMAC 2017
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Revised Selected Papers

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Abstract	We have analysed the basic characteristics of music playback at sight-reading of three two-line classic music selections of varying textures and complexity: a two-voice polyphonic musical piece, a theme and a variation of homophonic-harmonic musical piece. These characteristics serve as objective indicators of the musicians' skill of sight-reading, and the complexity of musical selection. Applying an original technique of eye movement recording without fixating the head, we studied the eye-hand span i.e. the time from reading the text to music playback. Our findings reveal, that the eye-hand span depends on the texture of the performed musical piece and inversely correlates with the number of errors as well as directly correlates with the rate of stability in the performance. This parameter may serve as an objective measure of the sight-reading ability. It is connected with the complexity of a musical piece and, presumably, characterizes the working memory capacity of musicians.

Keywords: (separated by '-')	Sight-reading - Eyetracking - Eye movements - Eye-hand span

Characteristics of Music Playback and Visio-Motor Interaction at Sight-Reading by Pianists Depending on the Specifics of a Musical Piece

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Abstract. We have analysed the basic characteristics of music playback at sight-reading of three two-line classic music selections of varying textures and complexity: a two-voice polyphonic musical piece, a theme and a variation of homophonic-harmonic musical piece. These characteristics serve as objective indicators of the musicians' skill of sight-reading, and the complexity of musical selection. Applying an original technique of eye movement recording without fixating the head, we studied the eye-hand span i.e. the time from reading the text to music playback. Our findings reveal, that the eye-hand span depends on the texture of the performed musical piece and inversely correlates with the number of errors as well as directly correlates with the rate of stability in the performance. This parameter may serve as an objective measure of the sight-reading ability. It is connected with the complexity of a musical piece and, presumably, characterizes the working memory capacity of musicians. AQ1

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1 Introduction

Playing a musical instrument is a complicated human activity, including physiological and cognitive processes taken in their multilevel complexity and simultaneity. At the physiological level this activity involves aural, visual, tactile and proprioceptive sensory systems. When playing the instrument, pianists execute complex coordinated patterns of hands and feet movements, visio-motor patterns of eye movements at sight-reading, head and body movements. Reading a musical text embraces processes of visual attention such as selecting and recognizing both single signs (notes and other signs in the musical language) and complex patterns (accords, rhythmic models), sensory and working memory of visual and aural modality, music-oriented kinesthetic memory which preserves motor patterns. With the manual performance of the recognized signs of musical notation, the working visual memory is transformed into kinetic patterns (automated motor skills, or "kinetic melodies", according to Luria [1]).

All these processes are executed through a sophisticated coordination of the visio-motor eye and hand activities. Thus, the analysis of eye movements at sight-reading of

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a musical piece (which directly or indirectly reflects the above mentioned processes) opens up a new opportunity for quantitative physiological study of this complex skill.

Sight-reading suggests performing an unfamiliar musical text for the pianist. This allows establishing a certain amount and structure of new visual information presented to the pianist. And it allows to exclude the challenging individual factor of a musical piece being previously learned from the process of playing a musical instrument. Moreover, the process percepting the visual information in the form of reading a note text allows utilizing a large amount of accumulated knowledge from the adjacent area of reading verbal texts, which facilitates the development of methodological approaches to studying such a complex type of human activity.

1.1 Sight-Reading as a Musical Skill

Sight-reading is performing an unknown piece at such a tempo and by that character as it was conceived by the composer, without a preliminary fragmentary playback. This performance shall be uninterrupted, comprehensive and considering all the author's instructions. If the skill of sight-reading is well-developed, visual and aural senses, motor skills closely interact with attention, memory, intuition and creative imagination of the musician [2, 3].

We have to admit, that in course of their studies the pianists do not always master the language of piano music with the required efficiency at primary and secondary educational music schools (colleges). It results from spontaneous accumulation of experience and is largely beyond the framework of a well-conceived system. Consequently, there are often gaps in the performing skills. Therefore, the task of primary education is limited to automatizing the system of "visual senses-aural senses-motor skills" [2, 3].

The text of piano music has both horizontal and vertical dimensions. Observations and experimental data show that the horizontal comprehension of the text is easier accounting for the practice of verbal reading. But a pianist faces with a more complicated task as he must look at two and even more lines at once (three-line and even four-line records of piano music was used by F. Liszt, S.V. Rakhmaninov, K. Debussy and other composers, and also in company scores).

For successful sight-reading it is vital to learn how to structure the musical language, i.e. to divide it into syntactic units with a definite meaning [2, 3]. The understanding of how a musical thought is developed helps foresee what will happen at the next stage and significantly facilitates sight-reading. The second component of the complicated sight-reading skill is the motor execution of what has been read by the performer in the musical notation [2, 3]. Three elements here are critical to achieve success:

1. Well-developed finger motor skill and basic motor patterns.
2. Ability to apply a rational finger notation in the process of reading (arrangement and alternation of fingers when playing a musical instrument)
3. Confident tactile orientation on the keyboard implies the ability to play without looking at hands (keyboard), which, in turn, requires a clear cognitive mapping of the keyboard.

Our research aims to reveal the physiological and cognitive processes involved in sight-reading. Our findings may be implemented in musical education for the development of quantitative assessment criteria of the musicians' professional skills.

1.2 Sight-Reading as a Psychomotor Processes

Piano notes are a complex set of signs, which combine a lot of factors affecting the character of eye movements while reading. First of all, the oculomotor activity depends on the complexity of the musical piece which, according to Souter [4], is stipulated by the following factors: (1) ocular complexity of a musical piece; (2) difficulty in transferring the ocular information into motor activity, which is determined by the experience of the musician; (3) difficulty in executing the motor instructions which comprise a definite finger position on the keyboard and a fine control over all the hand and arm muscles.

For a long time scientists have been studying eye movements in various aspects of human activity. Thus, a lot of effort has been invested into studying reading the verbal text in different languages, and this area has been thoroughly studied [5]. However, comparatively little research was conducted on reading the music text leaving numerous gaps in understanding this process. Yet, it was discovered that when reading a verbal text out loud [6] and at sight-reading of a musical piece with simultaneous performance [7–10] the position of visual fixation of the eyes in the notes precedes the performed passage (Fig. 1). On the basis of this phenomenon, ***eye-hand span*** (***EHS***) was introduced to estimate the span from the moment of reading the text up to its performance. From the very moment of fixation of the eye on the sign up to the moment of its performance, a number of physiological and cognitive processes proceed. First, the visual system perceives and deciphers visual information. Further on, the establishment and execution of the motor complex of movements take place. These constituent parts of the process as a whole most naturally require some time. Finally, a time span between the point of the gaze fixation on the musical notation and the performed note occurs [4]. The EHS parameter may be measured either (1) by the number of signs located between the note which is read and the performed note or (2) by the time from the end of the fixation to the moment the note is performed.

Sloboda [8] applied the methodology of the "fading screen" for EHS studies. In the experiments a musician was shown the monophonic notes on his screen. After a time span the duration of which was known only to the researcher, the screen was turned off, and the musician continued to play. Finally, the number of correctly played notes was estimated. The simplest measured parameter is the number of errors (notes that were played incorrectly) made during the performance. The errors were shown to correlate well with the reading skills of the musician: the most experienced musician's EHS was 6–8 notes and he made 3 errors, the least experienced musician's EHS was 3–8 notes and he made 73 errors [8].

To estimate the EHS the methodology of the "shifting frame" when a certain number of notes which preceded and followed the performed note were shown on the screen was also used. When this particular note was played, the frame moved forward [10]. This methodology revealed a correlation between eye movement's parameters and a number of notes following the performed note: among the experienced musicians, the duration of fixations decreased as the frame was enlarged, while EHS and the amplitude

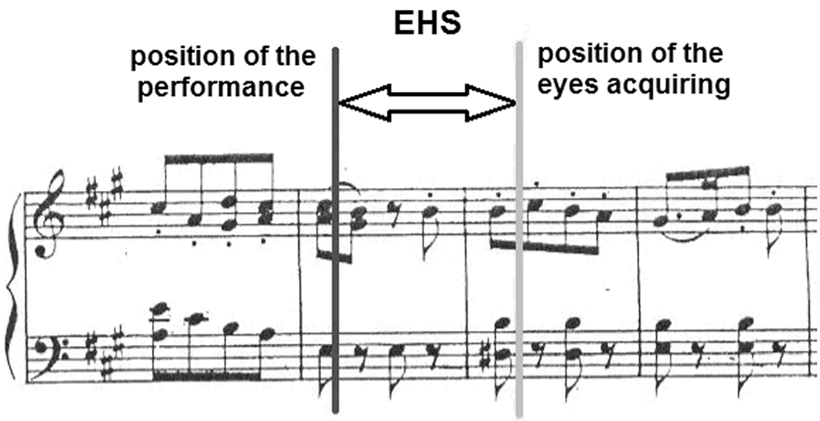

Fig. 1. The scheme of EHS (double-ended arrow) which is represented by a time span between the moment of the current gaze fixation at the musical notation (view point) and the moment performing the preceding notes which have already been read (performance point) (with modifications in accordance with [4])

of saccades increased. The results of the experiment also demonstrated that even the experienced musicians read 1–2 notes ahead most of the time, although the maximum preceding number of notes possible could reach 7 [10].

For the two-line notes, it was shown that the EHS varies greatly in the process of reading, but does not exceed 8 notes [7], and musicians read one chord forward in the event of text written in chords of three notes [11].

The EHS was first specified to have two components – one component is associated with the processing of visual information obtained through the foveal part, and the other – with the processing of information obtained through the parafoveal part of the retina [12]. Due to this fact, the professional pianists sometimes combine several notes into one sign (more frequently in passages) and that is why more information can be preserved in the buffer zone of the working memory [13].

From the technical point of view, the head retention while reading a musical text was a major problem in the experiments. Some researchers used a heavy motorcycle helmet with a video recorder to register the eye movements [11, 14], others immobilized the head with the help of a chin fixator [9, 15]. In later studies, lightweight and video quality-optimized video eye-trackers were used [16, 17]. In addition to head movements when playing a musical instrument, the pianist also makes movements with his head and torso which introduces additional difficulties when registering the eye movements. Another widespread problem is that a musician executes saccades at his hands, while sight-reading and at this particular moment the signal gets lost. Less experienced musicians execute more frequent saccades at hands than the experienced ones [4].

The recent literature on performance characteristics and eye movements at sight-reading is still rather limited. To the best of our knowledge no experiments where the eye movements could be registered without limitation to pianists' natural mobility were conducted. In all the studies referenced above, the eye movement's registration was performed with the head fixation, which inevitably affects the performance of the performed music text. In our work, we set out to investigate the characteristics of the performance with synchronous registration of eye movements at sight-reading of collections of pieces of different textures in natural conditions for pianists without fixating the head.

2 Methods

The study involved 16 students (9 men and 7 women at the age of 19–23) of Tchaikovsky Moscow State Conservatory specializing in piano. The musicians were offered one sheet of notes (2 pages) for sight-reading of three selected musical pieces of various textures and complexity: (1) Little prelude of J.S. Bach D-minor, two-voice polyphonic musical piece, (2) theme and (3) the first variation out of 13 variations of L. Beethoven for piano on the theme of aria “Es war einmal ein alter Mann” from opera “Das rothe Käppchen”, which is a homophonic-harmonic musical piece. Figure 2 shows two-line selections of each musical piece. These two-line pieces are called piano lines which include two lines for upper and lower registers (for right and left hands correspondingly) combined with accolade (curly bracket on the left) for performance by both hands.

Fig. 2. Examples of piano lines from musical pieces used in the experiments. The number of each fragment corresponds to the musical pieces (see above)

Musical piece *1* consisted of two pages of five piano lines each, 28 mm wide, with a minimum distance of 6 mm between the notes, and contained 488 signs (notes, alteration signs, pauses) in 47 measures (Fig. 2.1). Musical piece *2* contained mostly quavers (eighth notes) on two pages of five piano lines, 23 mm wide, with a minimum distance of 4 mm between the notes, and contained 373 signs in 38 measures (Fig. 2.2). In musical piece *3* semiquavers prevail (sixteenth-notes) on 2 pages of seven piano lines, 20 mm wide, with a minimal distance of 3 mm between the notes, and contained 465 signs in 38 measures (Fig. 2.3). In addition to the small font of the notes, this piece contains a lot of signs of alteration, which carry additional information related to playback of the notation text.

The musicians performed the task on the company's YAMAHA piano. The distance from the keyboard to the music stand was 28 cm, the distance from the eyes to the notes slightly varied during the performance and averaged about approximately 50 cm.

The registration of the eye movements in the process of reading the notation text was executed with the use of the portable eye tracker Arrington (Scene Camera Option, Arrington Research, Inc., USA) with frequency of 30 Hz without any restrictions on the mobility of the pianist. Such conditions for eye movement's registration in the experiment did not disturb the usual pose of pianists during performance of musical pieces.

In the full mobility conditions, we encounter the problem of the head shift, and to calculate the real position of the eye, it is necessary to combine two coordinate systems: the position of the eye in relation to the notes and the position of the notes in relation to the head. To solve this problem, an original software was developed to transform the coordinate position of the eye in relation to the notes, taking into account the head movements (Fig. 3).

Fig. 3. Track of eye movements before transformation of the coordinate position of the eye (on the left) and after transformation (on the right)

Playback of the perused musical text was recorded by professional voice recorder Olympus LS-5 and processed with use of programme Acoustica Basic Edition 6.0.

3 Results

3.1 Characteristics of the Music Playback at Sight-Reading

Investigating the sight-reading process includes analyzing the result of the process in question, in particular, the flow of sound of the performed music text. In addition to artistic and emotional characteristics, which are experienced biased, the musical sounding may be characterized by such objective indicators as the playback tempo, taken by the pianist, the stability of tempo maintenance at reading the whole fragment of work, and the number of errors made at reading the music text. The number of errors was defined by an expert on the basis of the expert evaluation by ear.

In music, the ***tempo*** is a unit of time and is traditionally measured by a metronome [18] as a number of beats per minute (bpm), time between two beats equals the quarter note. Since the music pieces provided for reading have – different time signatures, calculation of the tempo for each measure in a music piece was made using the formula:

$$V_i = (m * 60) / X_i \tag{1}$$

where V_i – tempo (bpm), m – the number of quarters in one measure of a music piece, X_i – playback length of one corresponding measure (s).

The tempo indicator for each musician was defined as an average of the tempo value over all measures during performance of a particular music piece.

Using non-parametric factor analysis of variance (according to the Kruskal-Wallis criterion), a statistically significant effect on the playback tempo rate indicator of the "specifics of a music piece" factor was revealed (H_2 = 27,31, p < 0,001). While the influence of the "individual" factor, which determines individual differences, turned out to be statistically unreliable (H_{15} = 13,19, p < 0,59). Based on the results of the variance analysis, we carried out a paired-comparison experiment and revealed statistically significant differences among the playback tempo of three music pieces (Fig. 4).

The variability of the playback tempo between the measures in the music piece characterizes ***the stability of the selected tempo maintenance***: a smaller variation of the playback tempo corresponds to a higher stability of the music playback, and vice versa. The stability indicator for each performance was determined as reciprocal of the standard deviation of the performance duration of measures in music pieces. In other words, the closer is the performance of the music piece to the ideal with the equal duration of each measure, the higher is the stability of tempo maintenance. By means of nonparametric factor analysis, it was shown that the influence of the "individual" factor proved to be highly reliable (H_{15} = 32,32, p < 0,006). But we did not reveal any statistically significant effect on the tempo stability of the "specifics of a musical piece" factor (H_2 = 3,25, p < 0,197),

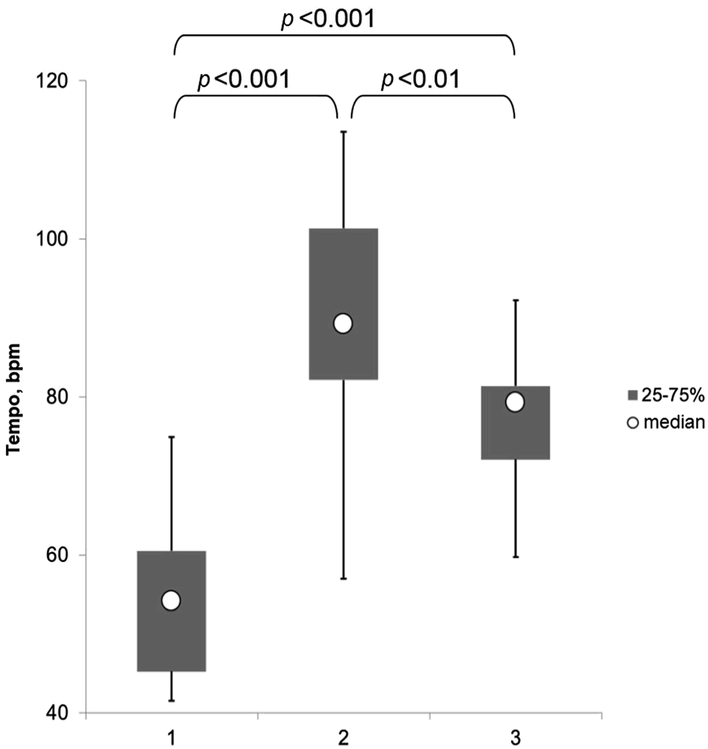

Fig. 4. Median values of the playback tempo for 16 musicians during the performance of three music pieces. The significance of statistical differences (*p*) was estimated in accordance with the Mann-Whitney criterion. References to the music pieces are given in the text above

The number of ***errors*** in a musical performance was normalized to 100 characters of the music piece, since all pieces included a different number of note signs (Fig. 5).

By method of non-parametric factor analysis, we revealed a statistically significant impact on the number of errors of the factor of a “music piece specifics” (H_2 = 12,65, p < 0,002), while the influence of the “individual” factor turned out to be quasi-reliable (H_{15} = 23,18, p < 0,09).

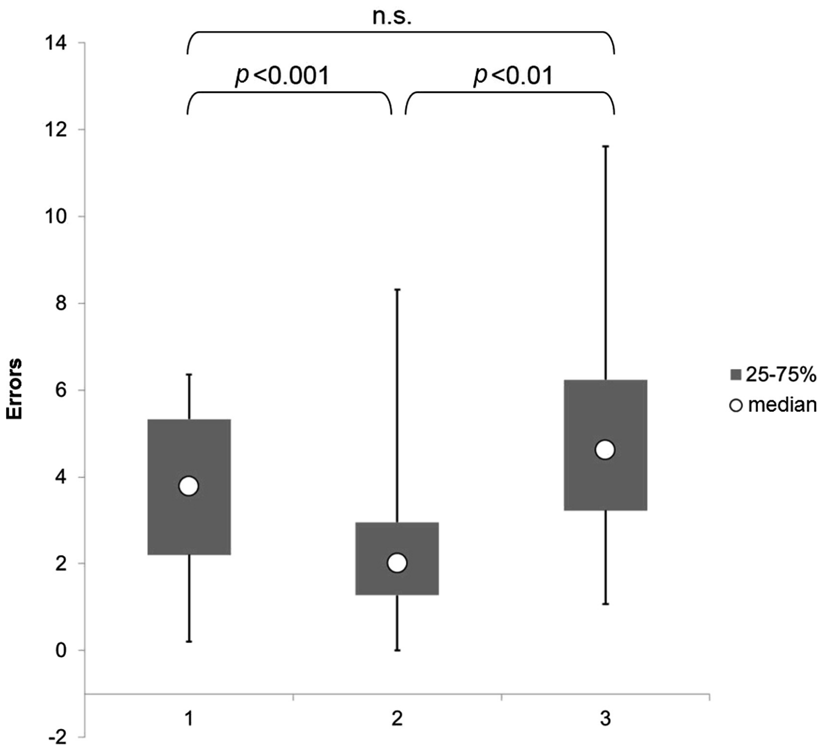

Fig. 5. Median values of the standardized error of 16 musicians during the performance of three music pieces. References are the same as for Fig. 4, n.s. – non-significant

3.2 Eye-Hand Span

The data on the eye positioning in the process of reading the notes and on performing those ones that have already been read allow us to assess the ***EHS*** index. EHS was determined once for each of the consecutive piano lines in a music piece at the moment when the gaze shifted to the next piano line. The final EHS index for each musician in the performance of each music piece was determined as an average for all piano lines of this music piece. Figure 6 shows EHS values (in musical symbols) averaged over all subjects for three musical texts, and Fig. 7 – distribution of EHS values.

According to the parametric two-factor analysis of variance (two-way ANOVA), a significant effect on the EHS value of the factor of the a "music piece specifics" ($F1_{2,285}$ = 17,48, p <0,001) and the "individual" factor ($F2_{15,285}$ = 15,57, p <0,001) were detected.

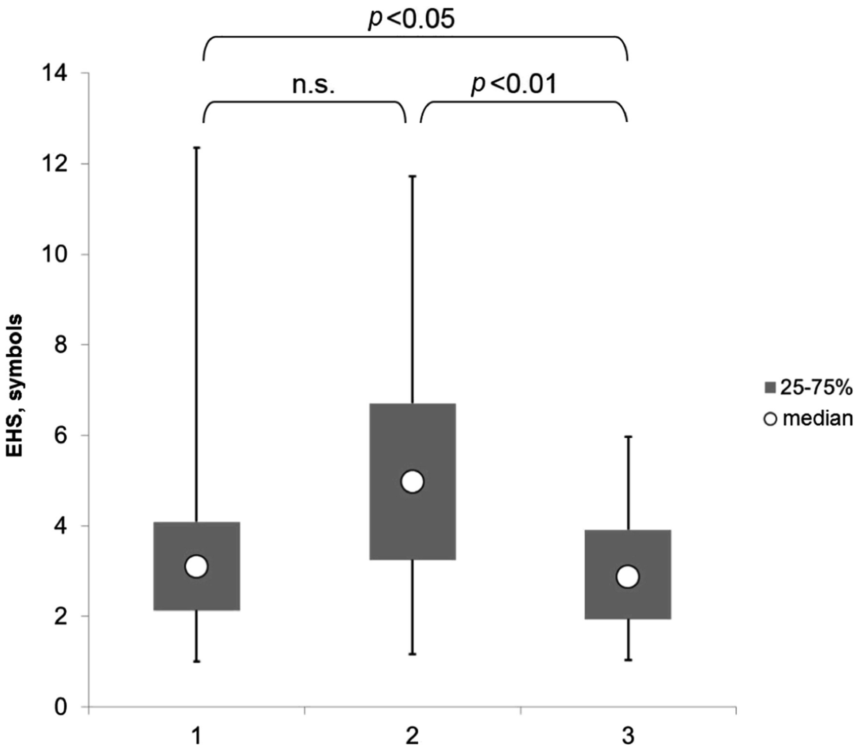

Fig. 6. Median values of EHS of 16 musicians during the performance of three music pieces. References are the same as for Figs. 4 and 5

We outlined a reliable inverse correlation ($r = -0{,}442$, $p < 0{,}01$) between the EHS value and the number of errors at sight-reading (skipped or incorrectly played note) – the objective indicators that characterize the quality of performance at sight-reading. It can be assumed that the bigger piece a pianist can hold in his working memory, the easier and more correctly he reads a piece from a sheet on the spur of the moment. A positive correlation between EHS and tempo stability was also revealed ($r = 0{,}37$, $p < 0{,}034$).

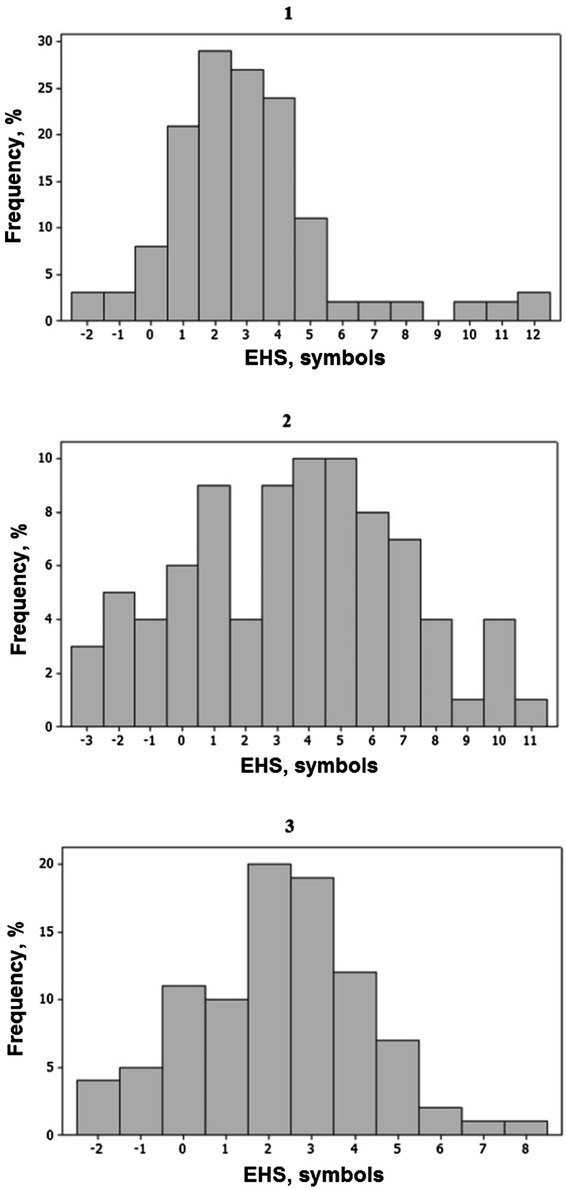

Fig. 7. Frequency distribution of EHS values of 16 musicians during the performance of three music pieces (marked by the reference numbers above the charts)

4 Discussion

The specificity factor of a musical piece influences all the analyzed characteristics of its playback except for the stability of maintaining the tempo. The complex analysis of playback characteristics of the musical text at sight-reading provides an opportunity to range the selected music pieces according to their subjective complexity. We assumed that the more complicated music piece is played, the larger the number of errors is. With other parameters being equal, at a slower tempo [4] and with less performance stability, the most complex was the music piece №3 ("Beethoven-variation"), while the music piece №2 ("Beethoven-theme") was the easiest to perform.

The stability of the selected tempo in which the significant influence of the "individual" factor was detected in combination with the number of errors committed, presumably may reflect the level of sight-reading skill of musicians.

Our results demonstrate, that the EHS is at its maximum at sight-reading of an easy musical text, and vice versa. Consequently, the EHS is a dynamic parameter that varies throughout the playback. As noted above, the EHS strongly correlates with performance errors, so it is most natural to assume that the pianist reads notes in more detail (makes more fixations) in the places where the note text becomes more complicated, and the EHS value decreases. During the performance of an easy-to-read musical piece, the pianist can make more saccades which run ahead of reading, and in this case the EHS value increases. Thus, in our study, the EHS parameter varied significantly both for each pianist and among pianists from −3 to 14 signs (Fig. 7), which is in line with other experiments with professional musicians: the EHS varied in the range of −2 up to 12 signs [10]. But the most frequent EHS value in our study was 2–3 signs, which is somewhat higher than when reading single-line notes obtained in another study – 1–2 signs [10]. Therefore, the EHS of 2–3 signs is more preferable when reading two-line notes. If the EHS value is lower, the performance quality worsens due to slowed down process of transferring the visual information into a motor response, and keeping a significant number of alternating sets of signs in the working memory is more difficult for a pianist in this type of activity.

The obtained results suggest that the EHS value can reflect the complexity of a music piece. In order to verify this assumption, an experiment which would allow to study the relation between the EHS and the errors made with a larger temporal span (for example, at the level of the measure in a music piece or even single notes) is needed.

5 Conclusions

The peculiarities of a musical piece influence all the examined characteristics of its playback except for the tempo stability.

The complex analysis of the music playback at sight-reading provides an opportunity to range the selected pieces according to their objective performance complexity. The examined qualitative characteristics may be used as the objective means for accessing the sight-reading skills among musicians to complement the experienced-based expert evaluation.

The EHS figures obtained in our research correlate well with the literary data, even taking into account a greater complexity for reading of two-line notes used in our work as compared to the single-line notes in literary data. The EHS figure may be used as an indicator of the "momentary" complexity of the note piece being read at a particular moment.

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