EYE MOVEMENTS IN READING, PICTURE INSPECTION AND MUSIC READING – WHAT DO WE KNOW?

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ABSTRACT

Background. While there is extensive literature on eye movements during the reading of a text or inspection of pictures (Rayner, 1995) there are only few reports about gaze behaviour during music reading (Lehmann, 2002). Yet musical sight reading implies an interesting experimental approach to the study of cognition, because vast amounts of input information must be handled and connected to complex output sequencing. This necessitates highly structured encoding as well as execution processes characterised by anticipation and expectation beyond the low level control of input features.

Aims. This paper provides a critical assessment of existing eye movement research in music reading and compares music and text reading to arrive at new research questions.

Contribution. In reading a text, WHERE decisions are mostly controlled by low level processes while WHEN decisions are more influenced by top down processes the longer the fixation durations last. In text reading, most data speak for a low level positioning process: non-optimal landing positions increase the probability of a second fixation on a word, for example. It is unknown if the perceptual span in music reading is more open to the vertical dimension while ordinary gaze progression is less predominant. Fixation durations are more influenced by comprehension i.e. matching to long term memory content, for example high frequency words need 242 ms and low frequency words 264 ms fixation duration. Regressions, i.e. leftward directed saccades in reading are rare and often found in difficult texts; perhaps a sign for the re-evaluation of expectations. Regressive saccades are more often seen in musical reading and mostly interpreted as an indicator of unusual time sharing processes.

Conclusions. Possible new designs for future research in musical reading experiments are proposed.

1. BACKGROUND

1.1. Eye movements in text reading

While there is an extensive literature about eye movements during text reading or inspection of pictures (for a review see Rayner, 1998) there are only few reports about gaze behavior during reading music (see Lehmann & McArthur, 2002; Lehmann, in press, for reviews). Studying musical sight reading bears a very promising experimental approach to research in cognition: a vast amount of input information must be handled and coupled to a complex output sequencing. This necessitates highly structured encoding as well as execution processes characterised by anticipation and expectation beyond the low level control of eye movement behavior implicated in text reading for encoding simple input features like empty spaces separating words.

Gaze behavior is characterized by fast position controlling eye movements, so-called *saccades*, that enable successive inspections of the regions of interest with the fovea, our retinal area with the highest visual acuity which is connected by a large neocortical neuronal network. Saccades are very fast movements of the eye balls that last between 30 and 80 ms depending on their amplitudes (distance from fixation point to fixation point). There are relatively long breaks of 90 ms up to several seconds between successive saccades, called *fixation durations*, during which the eyes hardly move and the visual information is being encoded (Galley, 2001).

In text reading, roughly speaking, most „where to go“ (location) decisions are controlled by *low level processes*. More specifically, the hypothetical construct ‚*perceptual span*‘ uses the empty spaces between two consecutive words for a computation of landing positions of successive saccades at roughly the centre of the next word (for a more sophisticated description see Radach & Heller, 2000). Skipping of the next word occurs only for very short and often redundant words like ‚*and*‘ or ‚*is*‘ or ‚ *the*‘ (in this example) and so on.

Decisions about „when to go“ (timing) that affect the durations of a fixations are widely, but not exclusively, influenced by *top down processes*, for example comprehension: A typographically or otherwise more difficult text induces longer fixation durations. Most fixation durations in text reading are short and in the order of 250 ms, i.e. we make 4 fixations in one second while reading text! Encoding time is long-term memory dependent: while high frequency words may only need a 242 ms fixation duration, words with comparably low frequency occurrence need a 264 ms fixation duration.Very short fixations of approximately 100 ms duration, so called „express fixations“, seem again to be controlled by more by low level processes. They occur in order to reposition the fovea near the *optimal landing position*, one or two letters left from the centre of the word. O‘Regan and Jacobs (1992) calculated a 20 ms cost for every letter outside this optimal landing position. Furthermore, the possibility of a second fixation on the same word increases with increasing deviation from this optimal point.

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Fixation durations are principally composed by two functional different processes: the first process encodes the information in the perceptual span and the second one computes the next position to be looked at, i.e. prepares the direction and amplitude of the next saccade. Sereno and Rayner (1992) surmised that the computation process for the next saccade needs at least 100 to 150 ms of a fixation duration leaving the very short time of 150 to 100 ms for the encoding process in the adult text reader.

The *asymmetrical perceptual span* in text reading is modified by learning and training. More and more letters to the right of the fixation point become relevant, corresponding to roughly 15 letters to the right or 2.6 degrees visual angle (on a normal DIN A 4 sheet of paper). However, the adjacent vertical lines are inexistent for reading although they lie only 0.6 degree below the active line. The progress in text reading is mostly sequential: 80 % and more of all fixations follow forward going saccades (in most languages moving from left to right). Regressions, i.e. leftward directed saccades in text reading are rare and occur more often in difficult texts, perhaps as a symptom of the re-evaluation of some disappointed expectations.

1.2. Eye movements in sight-reading

The width of the perceptual span in sight reading music is unknown. It should be larger than the 2.6 degrees found in text reading and it supposedly more open to the vertical dimension. Ordinary gaze progression to the right is said to be not so predominant as in text reading, i.e. regressions are more common in music sight reading (see Lehmann, in press).

2. METHOD

Because quantitative data are scarce in sight-reading research, we show some preliminary data from an eye movement study in which 52 subjects received seven trials at sight reading piano music at the keyboard. The subjects were paced with an accompaniment of a pre-recorded solo voice following Lehmann and Ericsson's (1993) methodology. The first two trials served as warm-ups and the next 5 trials were constructed as to contain increasing levels of musical complexity. Control condition conditions were other looking tasks such as picture inspection (PICTURE), the solving of RAVEN matrices (series D, 12 items), or tracking of a moving point with the gaze. Eye movements were also recorded between the different tasks. These resting trials were called „pauses". Eye movements were recorded with the horizontal and vertical *electrooculogram* (EOG) using specialized equipment (PAR-Elektronik, Berlin). Raw data were with 1 ms time resolution were stored on a computer hard disk. A software developed by Königstein (1989) identified off-line all saccades and blinks.

3. RESULTS

3.1. Fixation durations

Figure 1 shows mean fixation durations during the musical reading tasks (task number 11-17), the picture inspection task (number 19), and the RAVEN task (items number 41 to 43).

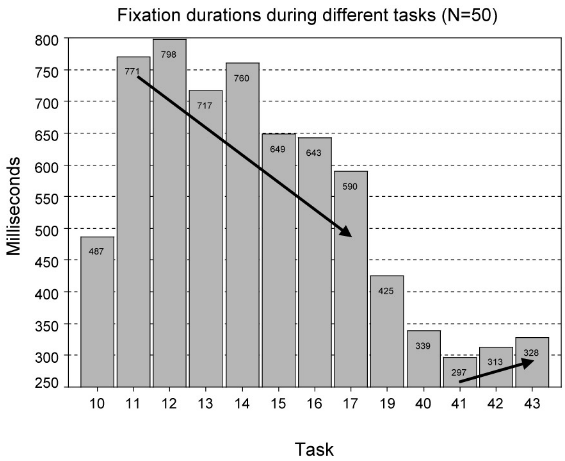

Fig 1. Fixation durations (medians) during different tasks: 10 = in the PAUSES before, between and after the five MUSIC SIGHT READING tasks, which are numbered 11 and 12 (warm up tasks) and 13 to 17 (sight reading tasks level 1 = 13, level 5 = 17); 11 and 12 are the warm up phases; 19 = during the PICTURE INSPECTION task; 41 to 43 = during the RAVEN tasks. The 12 tables of the RAVEN progressive matrices Series D are divided into an ‚easy'= 41, i.e. the first 4 tables, ‚middle' (the second 4 tables) = 42 , and ‚difficult' (the last 4 tables) task= 43; 40 = PAUSES in between the Raven tables.

It is surprising *how long the fixation durations were during sight reading music (from 590 up to 798 ms)*, which is more than double the time used in the RAVEN trials (297 to 328 ms). This can not be a result of a lower mental effort exerted in the RAVEN task, because the difficult RAVEN tasks (e.g., task number 43) requires substantial mental effort. In relation to the 250 ms fixation duration in text reading mentioned above, the 750 ms in music sight-reading are three times longer. Why are these fixation durations so long? A first hypothesis may be that the gaze amplitudes is larger in music reading than in the other tasks.

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3.2. Saccadic amplitudes

Figure 2 shows mean saccadic amplitudes during different tasks. We can see that amplitudes are indeed larger in music reading than in the RAVEN or PICTURE task.

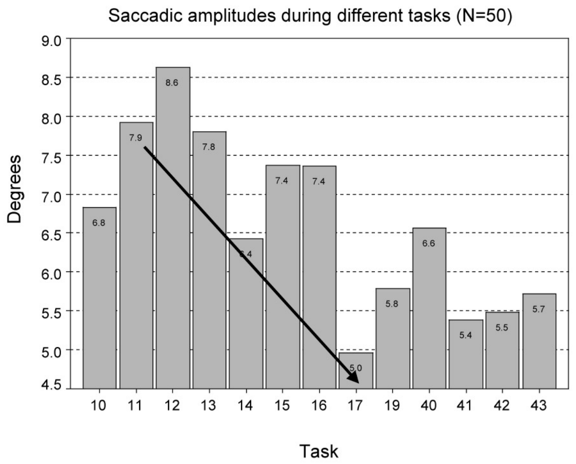

Fig 2. Saccadic amplitudes (medians) during different tasks (numbers represent the same tasks as in Figure 1; see Figure caption of Figure 1).

Interestingly, gaze amplitudes decrease with increasing level of musical difficulty in the sight-reading task. But the simple association of longer fixation duration with larger gaze amplitudes is not substantiated when one looks at the fixation duration as a function of gaze amplitudes in music reading (see Fig. 3)

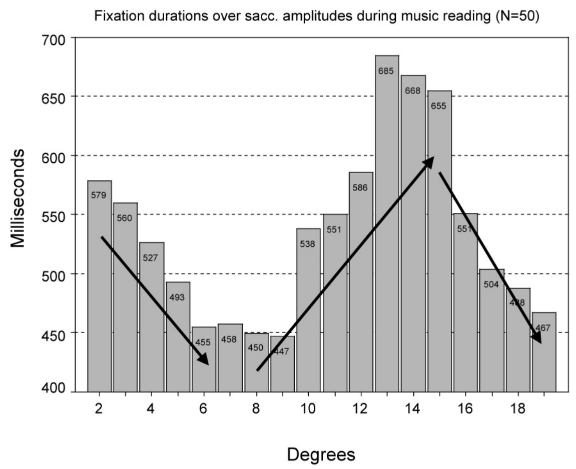

Fig 3. Fixation durations (medians of 10.178 saccadic intervals of 52 subjects) over increasing saccadic amplitudes during music sight-reading. The fixation duration before the saccadic movement was used. The fixation duration for 6 and 9 degree fixations are the shortest.

Here one finds the shortest fixation durations at amplitudes between 6 and 9 degrees while smaller as well as larger amplitudes are characterized by longer fixation durations. This means that a more complex relation must exist between fixation duration and position of the next saccade, and this relation likely differs from that found in solving the RAVEN task (see figure 4); here, the longer the distance to the next landing position of a saccade, the longer the fixation duration.

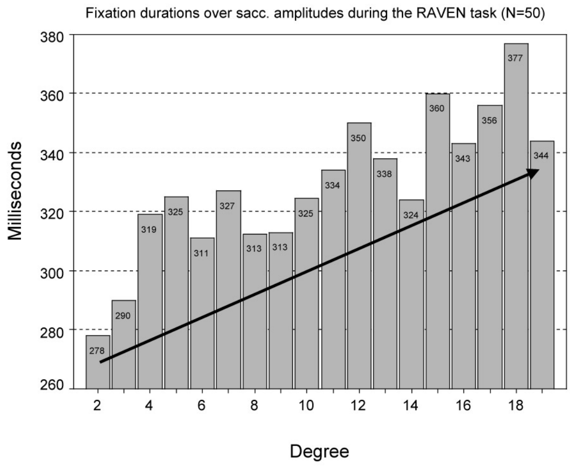

Fig 4. Fixation durations (medians of 18.786 saccadic intervals of 52 subjects) during the RAVEN task show a monotonic increase with saccadic amplitude.

3.3. Gaze directions

We are interested in the exact gaze positions of the music reader in order to interpret the ongoing information processes. Because the eye movement signal of the EOG contains an inherent drift it is very difficult to assess the true position of the gaze using this method. However, we calculated characteristics of the gaze directions which allowed some insight in the cognitive processes at work (see Table 1 in the Appendix).

During sight-reading the tendency to look orthogonally was most distinct when compared to the looking behavior in the RAVEN and PICTURE task. Downwards looking was the most prominent direction in sight-reading with 27.4 % (remember that 12.5 % would have been random behavior). *Left down* should have been the typical gaze direction for switching lines which is commensurate with the large gaze amplitude of 14.2 degrees and its diminuation to 8 degrees between sight-reading trials (see PAUSES).

Table 1. Gaze progressions in 8 directions. The percentage in every direction should be 12.5 %, if all directions were equally scanned. The sum of the 4 oblique directions should be 50 % for random scanning. Similarily, the mean saccadic amplitudes in every direction should be of the same values, if scanning occurred as a random behavior.

4. DISCUSSION

The complex looking behavior during sight-reading music (see fig. 3 and table 1) may be preliminarily interpreted in the following manner:

1) There seems to be an optimal gaze window of 6 to 9 degrees visual angle which requires the shortest fixation durations - when one calculates the gaze directions in this window two third of the gazes go downwards and upwards (not shown in the figures presented here)

2) The perceptual span, i.e. the spatial window from which useful information can be extracted, seems to be at least 9 degrees, which is more than three times the size of this window in text reading. If we interpret the increase in fixation duration in amplitudes of up to 15 degrees as costs for preprocessing the next useful landing position, than the perceptual span may be as large as 15 degrees. The fixation durations for larger gaze amplitudes decrease dramatically which may be appropriate for a guessing behavior.

3) At present the increasing fixation duration for gazes in the immediate vicinity of the optimal landing point looks paradoxical. In order to substantiate other speculative interpretations of our result we need to further control the exact location of the gaze.

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APPENDIX

TASK	MUSIC READING (52 subjects, 5 tasks, 10.178 saccades)		PAUSES before, between and after music reading (9 tasks, 52 subjects, 45.833 saccades)		RAVEN TASK (3 tasks, 52 subjects, 18.786 saccades)		PICTURE TASK (1 task, 52 subjects, 3.757 saccades)	
GAZE DIRECTION	% of all saccades	Mean saccadic amplitude	% of all saccades	Mean saccadic amplitude	% of all saccades	Mean saccadic amplitude	% of all saccades	Mean saccadic amplitude
Upwards	15.1	4.5	13.3	5.6	15.4	6.2	11.7	5.7
Right up	4.8	3.6	5	5.3	9.2	5.6	8.8	5.3
Right	11.9	3.5	14	6.5	13	4.6	16.4	6.1
Right down	10.8	6.2	12	8.2	10.1	6.1	13.4	6.7
Downwards	27.4	6.2	23.2	6.9	19.3	6.9	13	5.6
Left down	7.8	14.2	7.6	8.0	10.4	5.7	8.4	5.4
Left	15.2	10.9	16.8	7.4	13.7	6.7	17.5	5.7
Left up	7.1	5.2	8.1	7.2	8.8	5.8	10.8	6
All obliques	30.5		32.7		38.5		41.4	

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