Eye movements in developing readers: A comparison of silent and oral sentence reading

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We present sentence reading data from a large-scale study with children (N = 632), focusing on three key research questions. (1) What are the trajectories of reading development in oral as compared to silent reading? (2) How are word frequency effects developing and are changes differentially affected by reading mode? (3) Are there systematic differences between better and weaker comprehenders when reading silently vs. aloud? Results illuminate a number of differences between reading modes, including more and prolonged fixations in oral reading, along with less inter-word regressions and attenuated effects of word frequency. Weaker comprehenders were slower, especially in oral reading and showed less flexibility in the allocation of word processing time. Differences between reading modes can be explained by additional processing demands imposed by concurrent articulation and eye–voice coordination when reading aloud.

Keywords: Reading aloud; Eye movements; Children; Comprehension; Word frequency.

INTRODUCTION

Over the last three decades, our understanding of the perceptual and cognitive processes underlying skilled reading has grown substantially and visuomotor...
research has contributed significantly to this progress (see Radach & Kennedy, 2004, 2013; Rayner, 1998, 2009 for reviews). A number of well-developed quantitative models are available (Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reilly & Radach, 2006; Yang & McConkie, 2001) allowing accurate modelling of eye movements and contributing to the enhancement of our understanding of linguistic, visual, attentional, and oculomotor control mechanisms and their complex interplay.

Notwithstanding these advances, surprisingly little work has focused on children and the developmental aspects of reading. Compared to the substantial literature on adult reading, the number of publications on eye movements in developing readers is quite limited (see Blythe & Joseph, 2011; Radach, Schmitten, Glover, & Huestegge, 2008, for reviews). Especially noteworthy are a number of pioneering studies that laid much of the groundwork for today’s more elaborate research (e.g., Buswell, 1922; Taylor, Frackenpohl, & Pettee, 1960; McConkie et al., 1991; Rayner, 1986). These early studies examined elementary school students across various grades, with quantitative analyses mostly restricted to global parameters such as average fixation duration, number of fixations per 100 words, and overall regression frequency (see Table 20.1 in McConkie et al., 1991, for details). Not surprisingly, this work documented a steady reduction of fixation durations and number of fixations from grade to grade, whereas the decrease was much less pronounced for the proportion of regressive saccades (eye movements against the reading direction). It is noteworthy that very similar general trends appear in all four studies despite various differences in tracking technology, reading materials (sentences vs. paragraphs), and reading mode (silent vs. aloud).

McConkie et al. (1991) opened a new chapter in the analysis of children’s eye movements, introducing novel issues and research tools to the topic, such as frequency distributions of viewing time measures (see also, McConkie & Dyre, 2000), fine grain examinations of saccade landing sites within words (McConkie, Kerr, Reddix, & Zola, 1988; McConkie, Kerr, Reddix, Zola, & Jacobs, 1989), and the first quantitative analyses of relations between eye movement parameters and psychometric reading assessments. This was also one of the first studies in which the now common dissociation of viewing times into initial fixation durations, gaze duration and total viewing time (Inhoff & Radach, 1998; Rayner, 1998) was applied to research on developing readers. The idea of this decomposition is to delineate the time course of word processing into time intervals that reflect early orthographic and lexical processing (initial fixations), full lexical access (refixation times) and time spent on integration of word meanings into representations on the sentence and text level (rereading times). The analyses of word viewing times in the present paper will follow this logic (see Radach & Kennedy, 2004, for a discussion).

A prime example demonstrating how critical information can be overlooked when relying solely on global measures is the case of regression rates. The
overall proportion of regressions (leftward saccades) seems to stay fairly constant across readers from different grades. However, when analysing the data on a word-based level it becomes apparent that intraword regressions (regressive refixations within the same word) become less frequent, whereas interword regressions (saccades going back to text left of the currently fixated word) become more and more frequent as reading skill develops (McConkie et al., 1991). Intra- and interword regressions reflect qualitatively different cognitive processes in adult reading, with many regressions executed in the interest of high level comprehension (e.g., Inhoff, Weger, & Radach, 2005). Assuming that this is also the case for beginning readers, the age-related increase in interword regressions may reflect a qualitative change from a dominance of decoding-related effort towards allocating more and more cognitive resources to comprehension.

Recent studies examining eye movement patterns in children have used experimental designs to examine specific research questions in specific age ranges. These questions include differences between children and adults in perceptual span size (Häikiö, Bertram, Hyönä, & Niemi, 2009; Rayner, 1986), word length and frequency effects (Blythe, Liversedge, Joseph, White, & Rayner, 2009; Blythe, Häikiö, Bertram, Liversedge, & Hyönä, 2011; Huestegge, Radach, Corbic, & Huestegge, 2009; Hyönä & Olson, 1995; Joseph, Liversedge, Blythe, White, & Rayner, 2009; Joseph, Nation, & Liversedge, 2013), and binocular coordination (Blythe, Liversedge, Joseph, White, Findaly, & Rayner, 2006). Very few studies have so far focused on higher level processing beyond the word level (e.g., Joseph et al., 2008; Joseph & Liversedge, 2013; Vorstius, Radach, Mayer, & Lonigan, 2013). Taken together, data collected in this work suggest that with development, the spatial extent of the perceptual span increases, word viewing times decrease, fewer fixations and regressions are made, and fixation probabilities and refixation frequencies are reduced. Manipulations of word processing difficulty are generally reflected in children’s eye movements, although often such effects are less clear cut compared to skilled reading in adults (see Blythe & Joseph, 2011, for a comprehensive review).

The present work is aimed at further advancing our understanding of reading development using a combination of experimental and corpus based methodology. Similar to the materials developed by Schilling, Rayner, and Chumbley (1998) and Kliegl, Grabner, Rolfś, and Engbert (2004), participants were asked to read a sample of single, unconnected sentences. These sentences can be analysed as a textual corpus similar to the English (Vitu & McConkie, 2000) and German (Radach & McConkie, 1998) Gulliver’s Travels corpora, and the English/French newspaper corpus (Pynte & Kennedy, 2006). However, due to the inclusion and variation of well-controlled target words, our materials also allow for factorial analyses strategies (see Radach, Huestegge, & Reilly, 2008, for a similar approach).

To date, no direct comparison of eye movements in oral vs. silent reading in children has been published. However, such a comparison is interesting from two different, but related perspectives. First, from a theoretical point of view, we
know little about how, in comparison to silent reading, the more complex process of reading aloud is controlled. This includes the question of how the addition of a language production component in oral reading influences the ongoing processes of spatially distributed information acquisition, word recognition and comprehension. A related topic concerns the coordination of both processing streams, receptive and productive, as evident in the eye–voice span (Inhoff, Solomon, Radach, & Seymour, 2011). Second, from an educational point of view, oral reading is the starting point of development and the focus of typical early reading curricula. Reading aloud provides an easy way for teachers to track errors and often oral reading performance is assumed to provide a valid and reliable ad hoc assessment for the general reading ability of a child. In our view, it is not quite clear whether such a generalization is justified, as relatively little is known about the precise nature of the differences between silent and oral reading, especially regarding the dynamics of development in both modes of reading.

Relating reading mode and comprehension, it appears quite reasonable to assume that reading aloud enhances comprehension because readers can benefit from additional auditory input as they are monitoring their own articulation (Kragler, 1995). Moreover, the ongoing process of grapheme–phoneme conversion might draw more resources towards sublexical processing units, which may benefit both word recognition and comprehension (Kragler, 1995; Miller & Smith, 1990; Prior & Welling, 2001; Swalm, 1973).

The alternative view, that reading aloud may hinder comprehension goes back to Jones and Lockhart (1919), who first suggested that readers must devote extra resources to pronunciation, intonation, monitoring, etc., leaving less capacity for comprehension. As one specific variant of this view, it has been suggested that processing of a word may come to an end after its pronunciation when reading aloud. In this case the focus on the grapheme-to-sound route may actually impede access to the more direct lexical and/or semantic information (Juel & Holmes, 1981). These authors also suggested that the effect of reading mode on comprehension may depend on the state of development, with beginning and struggling readers showing better achievement during oral reading, readers in higher grades (3rd and 4th) showing no difference and skilled (adult) readers exhibiting better results during silent reading. The question of whether such a developmental trajectory is reflected in eye movement parameters has yet to be answered.

The present study is part of a large-scale research project. The general design combines cross-sectional and longitudinal comparisons, but, as a first step, the present paper reports cross-sectional data of grades 1 to 5, collected during year one of the project. Due to space limitations we decided to focus on analyses of viewing times (although selected spatial parameters will be reported), examining three main research questions: (1) What are the trajectories of reading development in oral as compared to silent reading? (2) Using word frequency as a standard way to manipulate word processing difficulty, we raise the question
of how frequency effects change over the course of reading development and how this change is differentially affected by reading mode. (3) Finally, we explore the effects of comprehension level on eye movements, asking whether there are systematic differences between stronger and weaker comprehenders in the processing of words when reading silently vs. aloud.

**METHODS**

**Participants**

Participants were part of a large-scale study on reading development in which 1906 children from pre-k through 5th grade were tested in year one. Out of this sample, 632 children in grades 1–5 were asked to read a sentence both silently and aloud while their eye movements were being monitored (n = 153, n = 117, n = 134, n = 111, and n = 117, respectively, from grade 1 to 5). Participating students attended classrooms in different schools in North Florida and were ethnically and economically diverse. Written informed consent was obtained from a parent or legal guardian and child assent was collected at the beginning of the testing session. **Table 1** presents key demographic information.

**Materials**

Participants were asked to read simple declarative sentences, including 3 practice and 48 experimental sentences in each reading mode (102 trials total). Experimental sentences consisted of 9–14 words and had a mean length of 62.6 (SD = 3.1) letters in the silent condition and 62.9 (SD = 3.5) letters in the aloud condition. Since the data collected in this study are intended to be combined with other assessments of reading for analyses of individual

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Key demographics for analysed data sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>1</td>
</tr>
<tr>
<td>Age (year; month)</td>
<td>7;0</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
<td>51.2%</td>
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<tr>
<td>Race</td>
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<tr>
<td>Black / African American</td>
<td>20.3%</td>
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<tr>
<td>Asian</td>
<td>0.8%</td>
</tr>
<tr>
<td>Others</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

1st grade, n = 123; 2nd grade, n = 115; 3rd grade, n = 134; 4th grade, n = 111; 5th grade, n = 113; N = 596. Some participants did not provide all demographics, therefore not all categories add up to 100%.