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Eye movements during the reading of word problems. Advances in the use of eye tracking data

Mathematical Word Problems

Word problems are of increasing importance in Mathematics Education (Boonen, de Koning, Jolles, & van der Schoot, 2016). They are used in textbooks and large-scale studies like PISA (OECD, 2013). Moreover, modelling tasks are usually presented in word problems (Leiss, Schukajlow, Blum, Messner, & Pekrun, 2010). *Mathematical word problems* (MWP) are considered mathematical tasks in which relevant information is presented as text rather than in mathematical notation (Verschaffel, Greer, & De Corte, 2000). Hence, both reading comprehension and mathematical abilities contribute to successful MWP solving (Daroczy, Wolska, Meurers, & Nuerk, 2015; Kintsch & Greeno, 1985). Key activities during reading are performed by the eyes (Rayner, Pollatsek, Ashby, & Clifton, 2012). Accordingly, eye tracking has been used in research on MWP solving (e.g. Hegarty, Mayer, & Green, 1992). Nevertheless, despite the increasing relevance of eye tracking in Mathematics Education (Barmby et al., 2014), research on MWP solving using eye tracking is still scarce.

Eye Movements and Mathematical Word Problem Solving

Eye movements during reading consist of *fixations*, during which the eyes rest on a location and are able to extract information. Between fixations, the eyes move to the next location in rapid *saccades*, during which perception is almost completely suppressed. Parameters of eye movements can be broadly categorized into three categories (Lai et al., 2013): *Temporal* measures include fixation times, total reading times, re-reading times etc. *Count* measures refer to the number of events, e.g. fixations or saccades. In contrast, *spatial* measures refer to locations, distances, directions and sequences of events, for example the direction of saccades, if readers switch between certain elements of the text, etc.

Research in Mathematics Education has mostly made use of temporal and count measures in the past. In particular, research on WP solving has focused on comparing fixation times on specific elements of the WP, for example relational terms and numbers, or on counting re-readings (Hegarty et al., 1992). This was adequate since studies analyzed prototype MWP that usually only consist of a limited amount of text like compare problems (Daroczy et al., 2015). In contrast, recent MWP usually consist of a larger amount of text and require more complex operations. These MWPs cannot as easily be analyzed through focusing on temporal and counting measures for specific elements.

The present research

We present two studies in which we explored ways to analyze eye movements during MWP solving more comprehensively. This way, we try to extend the use of eye tracking for analyzing processes of solving more complex MWP.

Study 1: Exploring sequence chart rating

A key interest of research on reading of mathematical texts in general and of MWP in particular has been the relation between text and pictures. Commonly based on models of dual processing (e.g. Paivio, 1986), strategies have been identified that describe how students make use of pictures to understand or solve texts. Eye tracking has been used in this field of research (Beitlich, Obersteiner, & Reiss, 2015), but commonly spatial measures of eye movements have not been included that take into account sequences of eye movements during reading. In contrast, Jian and Wu (2015) rated *scan paths* of participants' eye movements to discriminate between different reading strategies for instructional science texts. Scan paths are a depiction of the readers' fixations and saccades, laid over the presented stimulus. This method is relatively time consuming and raters need to be trained very well to identify strategies in scan paths.

In an explorative approach, we transferred Jian and Wu's method (2015) and further developed the scan path rating (Tatsidou, 2017). Instead of scan paths, we used so-called *sequence charts*. In sequence charts, the area that is fixated is mapped on a time-axis, with different colors representing different areas of the stimulus (see Fig. 1). Compared to scan paths, sequence charts integrate a visualization of time, which makes it easier to evaluate the reading process.

For testing the method of sequence chart rating, we took recordings of 19 students reading 4 illustrated MWP. For the rating, we provided two independent raters with a manual containing prototype scan paths for four different strategies of integrating pictures and text: text-diagram referencing, text first, picture first, and text only (Jian & Wu, 2015). We asked the raters to compare the recordings and to choose one of the four categories. The rating of $N = 56$ recordings resulted in a substantial inter-rater agreement, $\kappa = .75$; $p < .001$. This indicates that the method is a promising approach for integrating a spatial measure that can be assessed very economically.

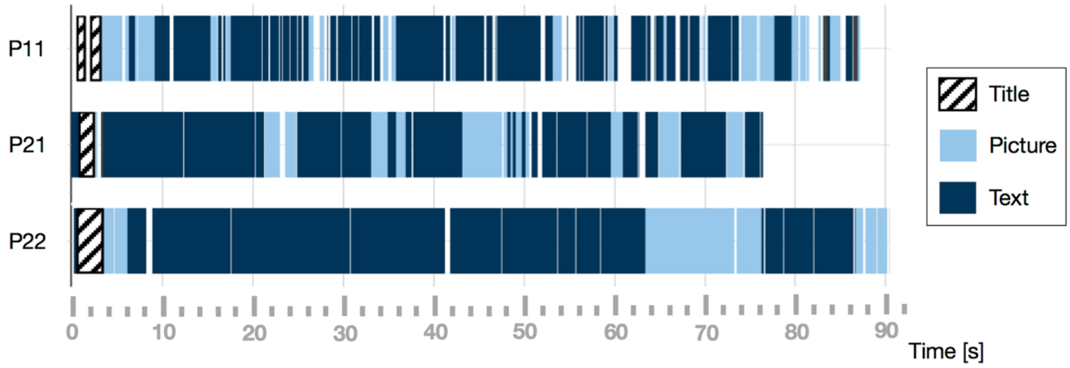

Fig. 1: Example seqence charts of three participants' reading patterns. The charts were rated as text-diagram referencing strategy (top), text-first strategy (middle), and picture-first strategy (bottom).

Study 2: Learning form Research on Reading

Our second approach included the adaption of *global measures* of eye movements during MWP solving. These measures do not relate to specific elements of the MWP but describe characteristics of eye movements of the process of MWP solving as a whole. Examples for these measures are *reading speed* and *mean fixation duration*. Adopting these measures enable the comparison of MWP of different length, type and form, since global measures are usually standardized. A detailed description of the method, results and application are described by Strohmaier, Lehner, Beitlich, and Reiss (2018).

Discussion

This brief paper included two novel explorative approaches to use eye tracking data of MWP solving. This adds to existing research that commonly focuses on temporal and counting measures and on specific elements of prototype MWP.

Our observations indicate that the use of eye tracking for MWP solving is not fully exploited in current research. More importantly, we think that important processes can be observed better when the potential of eye tracking is fully utilized. Arguably, this is especially true for mathematical tasks that include reading comprehension since eye movements are a key indicator for processes of reading. First, we proposed the method of sequence chart rating. The method offers a time-efficient way to combine a qualitative rating with quantitatively preprocessed data. We assume that the substantial agreement could be further improved by developing more elaborated manuals for raters. Furthermore, a larger amount of strategies could be taken into account.

Our second approach to use global reading parameters provides better comparability between problems, individuals or subjects. We think this opens new ways and perspectives on analyzing prerequisites and processes of solving word problems in mathematics, but also in other fields of research. In conclusion, we think the full potential of eye tracking in Mathematics Education has yet to be explored.

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