Mind the reading mind: a multifaceted and methodologically diverse approach to investigating the role of attentional control and feedback in reading comprehension

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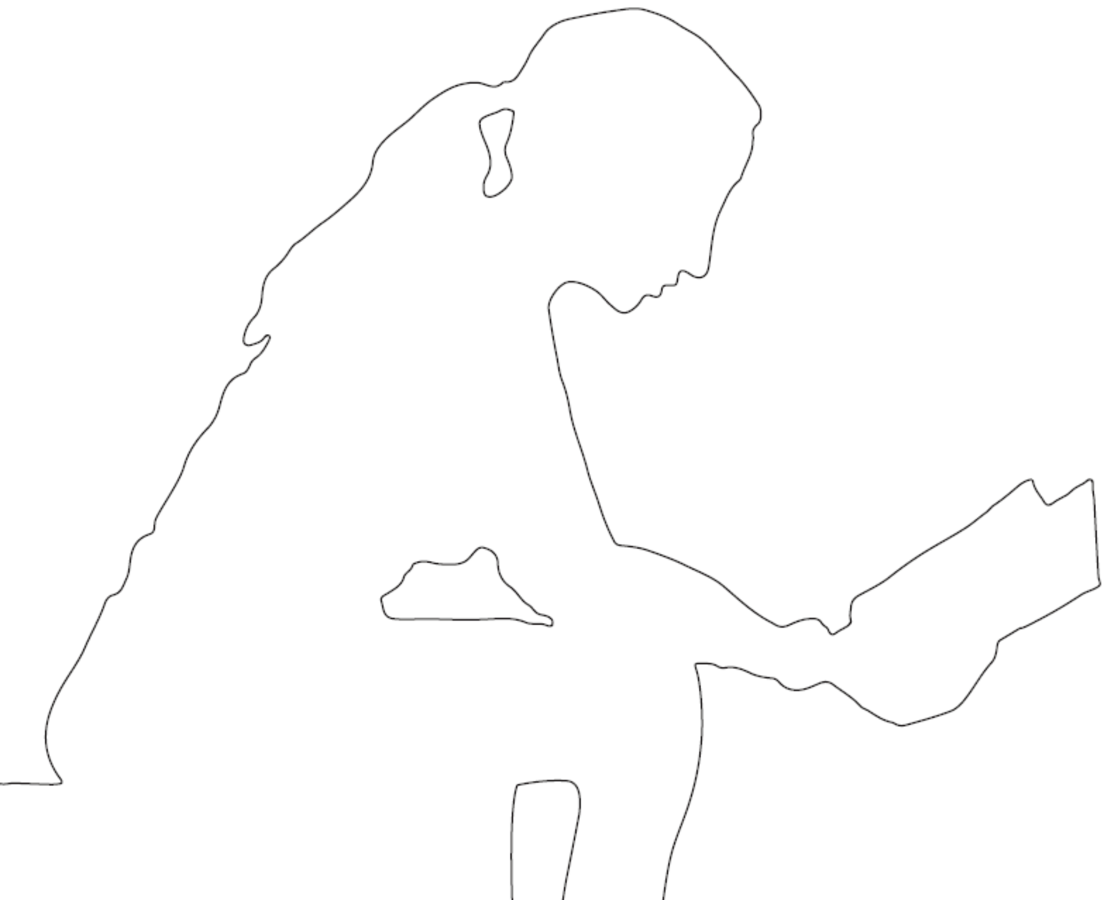


Chapter 1

General Introduction

Introduction

An essential tool for success and survival in school, as well as in private and professional life, is reading comprehension. Whereas in the early years of education there is a focus on *learning to read*, in later years, the focus shifts to *reading to learn,* a phase in which reading comprehension is a crucial vehicle for learning (see Chall, 1983; Pearson et al., 2012). To comprehend, and thereby learn from, a text, students must be able to extract the main idea from a text, understand relationships between parts of text, and link information in the text to their background knowledge or personal experiences (Organisation for Economic Cooperation and Development [OECD], 2019). Yet, still too many students experience difficulties with these skills.

Results of PISA-research over the last decade have demonstrated that, internationally, an average of 20% of 15-years old children do not reach a basic level of reading comprehension (OECD, 2010; 2014; 2016), defined as the ability to "identify the main idea in a text of moderate length, find information based on explicit, though sometimes complex, criteria, and reflect on the purpose and form of texts when explicitly directed to do so" (OECD, 2019, p. 86). In the most recent PISA-study, conducted in 2018, this percentage increased to 23%, indicating that nearly one in four children had not developed the reading comprehension skills necessary to learn from texts (OECD, 2019). Additionally, in the 2020 U.S. News and World Report ranking of *Best Countries for Education,* for half of the top ten ranked countries the average reading performance of 15-years olds had declined since the previous PISA research in 2016 (see OECD, 2019; U.S. News, 2020). Coupled with the recent PISA results this is an alarming decline in students' average reading performance. However, reading comprehension problems are not limited to primary and secondary education levels, but are also seen in higher education where reading comprehension difficulties are a common obstacle for learning (see e.g., Andrianatos, 2019; Bettinger & Long, 2009; Gorzycki et al., 2016).

Reading comprehension is seen as a complex skill (see e.g., Castles et al., 2018; Hoffman, 2017). Although in 1986, Gough and Tunmer presented the "simple view" of reading comprehension, defining it as the product of decoding skills and linguistic skills, (Gough & Tunmer, 1986; see also Hjetland et al., 2020), researchers have debated whether a "simple view" adequately explains the complex process of reading comprehension. For example, research demonstrates that decoding and linguistic skills only explain approximately half of the variance in reading comprehension skills for older children and adolescents (see e.g., Ouellette & Beers, 2010; Tilstra et al., 2009). Further, other skills and processes have been found to be critical components of reading comprehension, including strategic reading behaviour, attentional control, and motivation (e.g., Arrington et al., 2014; Kendeou et al., 2014; Kieffer et al., 2017). Conners (2009) found that for children as young as 8 years old, attentional control was an important factor in reading comprehension, uniquely explaining 10% of the variance in reading comprehension skills, and concluded that attentional control should be seen as a third component of the simple view of reading.

Given the complex nature of reading comprehension, it follows that understanding comprehension requires a multifaceted approach that incorporates the multiple skills necessary for comprehension to occur (Israel & Reutzel, 2017). Such an approach must not only consider the product of reading comprehension (i.e., determining whether the reader has understood what has been read) but also the processes underlying reading comprehension (i.e., determining which cognitive and behavioural actions are applied during reading, and how they are applied; McNamara & Kendeou, 2011). In this dissertation, the focus is on the processes underlying reading comprehension. A thorough understanding of these underlying processes of reading comprehension is fundamental to (1) understanding individual differences in reading comprehension and (2) developing effective methods for improving reading comprehension (see Castles et al., 2018; Hoffman, 2017; Israel, 2017; Kendeou et al., 2014; McNamara & Kendeou, 2011).

A multifaceted approach to understanding reading comprehension necessitates a diversity of methodological approaches (see Israel & Reutzel, 2017; RAND Reading Study Group, 2002). For example, randomized controlled trials (RCTs) provide insight into the causal relations between variables, and are important for testing the effects of comprehension instruction and interventions. Replication studies provide insight into the generalizability of findings across participant characteristics and contexts (see Merkelbach, 2018). Research syntheses provide insight into the theoretical underpinnings of reading comprehension, and help to establish a knowledge base that can be used to inform educational practice.

In the current dissertation we apply a multifaceted and methodologically diverse approach to gain insight into both individual differences in reading comprehension and the effectiveness of instructional methods. First, we investigate the role of internal factors related to reading comprehension, namely attentional processes during reading, by combining traditional psychological measures (e.g., reading comprehension/vocabulary tests, questionnaires, self-reports) with psychophysiological measures and methods (e.g., EEG, levodopa administration, genotyping) to get a more thorough picture of what is going on when students extract meaning from text. Second, we investigate the role of external factors on reading comprehension, namely the effects of feedback on reading comprehension and on the processes underlying reading comprehension. More specifically, we conduct a meta-analysis of research on the effects of feedback on reading comprehension and on the cognitive and affective processes related to reading comprehension.

Attentional Control and Reading Comprehension

Attentional control is a critical aspect of reading comprehension, affecting the readers' comprehension of text (Arrington et al., 2014; Conners, 2009; Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Sanders et al., 2017; Smallwood et al., 2007, 2008; Soemer et al., 2019). Yet, measuring attentional control during reading is challenging because the act of measurement itself can be a distraction to the reader. In the second chapter of this dissertation, we examine the role of attentional control in reading comprehension and review methods for measuring attentional control. We also investigate an alternative method for measuring attentional control, one that does not interrupt the natural process of reading and thus does not introduce a distraction to the reader.

It is a familiar view in universities, high schools, or study centres: Students sit at desks, or in front of a computer, reading long stretches of text they are expected to study for their courses. Staying focused while reading and studying such texts is an increasingly challenging activity given the distractions that students face in our modern-day society (see Gazzaley & Rosen, 2016; Rosen, 2017; van der Stigchel, 2018). The amount of distracting information with which students are surrounded has increased immensely over the past years as a consequence of the increased accessibility and capabilities of digital devices. Often next to the books and papers on students' desks are mobile phones, tablets, or computers, with multiple tabs open, waiting to distract the reader with information that is unrelated to the text being read. This task-irrelevant information coming from digital devices, including text messages, posts on social media, e-mails, and videos, distracts students on average 11 to 12 times per hour (Calderwood et al., 2014). It is not only this increased amount of task-irrelevant information coming from digital devices (i.e., external distractors) that causes distraction, even *thinking about the possibility* that there may be new posts on social media, new messages, or new e-mails can cause distraction (i.e., internal distractors; see also Gazzaley & Rosen, 2016; Schad et al., 2012; Smallwood, 2011). Similar to external distractors, such internal distractors draw the attention of the reader away from the task at hand, forming a challenge for readers to control their attention.

In their book called *The Distracted Mind*, Gazzaley and Rosen (2016) metaphorically describe attentional control as operating a spotlight. To operate the spotlight, one has to decide not only if the spotlight (i.e., focus) should be turned on or off, but also to anticipate when, where, and for how long the spotlight should be turned on.

Translating this metaphor into attentional control during reading, the reader has to focus attention (i.e., turn the spotlight on), from the moment he or she starts to read, until the entire text has been read and a mental representation of the text has been formed (i.e., anticipate when and for how long the spotlight should be turned on). In addition, during reading, the reader has to select and process relevant information from the text (i.e., decide where to focus the spotlight) in order to link it to background knowledge.

Research has shown that people who are better able to regulate their attention during reading (i.e., the more skilled operators of the spotlight), have a better understanding of what they read (e.g., Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Sanders et al., 2017; Smallwood et al., 2007, 2008; Soemer et al., 2019). However, one of the caveats in research on attentional control during reading, and one that serves to potentially threaten the ecological validity of the results, is the lack of direct measures of attentional control, that is, measures that do not interrupt the natural reading process (see Smallwood & Schooler, 2015). Although researchers can create experimental circumstances that challenge readers to control their attention during reading (e.g., by manipulating task difficulty or watching a sad movie just before a task; Feng et al., 2013; Smallwood et al., 2009), there is no button to turn attentional control on and off. As a consequence, most research on attentional control during reading has been based on self-reports of attentional control (see also Smallwood & Schooler, 2015). A small number of researchers have searched for objective indicators of attentional control, for example, by studying eye movement patterns during reading (e.g., Reichle et al., 2010; Schad et al., 2012; Uzzaman & Joordens, 2011), but the large majority of studies have been based on self-reports as indicators of attentional control during reading. Self-reports have two limitations, namely that the reports are based on subjective information, and that the act of self-reporting on attentional control during reading interrupts the natural reading process (for a more thorough consideration of the limitations of these self-reports, see Chapter 2). Finding an objective, non-intrusive, reliable measure of attentional control during reading could improve our understanding of attentional control during reading, and provide insights into individual differences in attentional control and the effects of these differences on reading comprehension. Therefore, in Chapter 2 we test the value of frontal TBR during reading, an EEG-measure that has been related to state attentional control during task performance in previous research (Braboszcz & Delorme, 2011; van Son et al., 2019a), as an indicator for attentional control during reading.

The Influence of Dopamine on Attentional Control and Reading Comprehension

To gain further insight into individual differences in attentional control during reading and reading comprehension, in the third chapter of the dissertation we study neurobiological – specifically dopaminergic – processes that underlie attentional control and reading comprehension. In a randomized double-blind placebo-controlled trial, we investigate the effects of administering levodopa, a precursor of dopamine (DA) in the brain, in two groups of students; a group of students carrying the DRD4 7-repeat allele (DRD4 7+), which is related to lowered levels of DA in the brain (Ariza et al., 2012), and a group of students not carrying the DRD4 7-repeat allele (DRD4 7-). First, we test the effects of administering levodopa on attentional control by using the objective EEG-measure (frontal TBR) that was examined in the second chapter of this dissertation, and a retrospective self-report of attentional control. Second, we investigate the effects of administering levodopa on reading comprehension.

Several studies have been performed over the last two decades to investigate the role of DA, and fluctuations in DA, in cognitive performance (for reviews, see Nieoullon, 2002; Westbrook & Braver, 2016). However, the exact influence of DA and fluctuations in DA in the brain on attentional control is not yet clear. The prefrontal cortex (PFC), a brain region that is rich in dopamine receptors and highly sensitive to fluctuations in dopamine (Cools & D'Esposito, 2011; Cools & Robbins, 2004), is involved in both attentional control and memory processing (see e.g., Berke, 2018; Fan et al., 2001; Gazzaley & Rosen, 2016; Melara, 2004; Miller & Cohen, 2001). Attentional control is the ability to sustain attention for prolonged periods of time. Attentional control is important during tasks such as reading that require the use of working memory to integrate information and to update knowledge in memory. Attentional control during such tasks is influenced by DA transmission in the brain (Boulougouris & Tsaltas, 2008; Braver & Cohen, 2000; Westbrook & Braver, 2016). Studies on patients with disorders associated with reduced DA transmission in the brain have demonstrated that this reduced transmission leads to problems in attentional control (Nieoullon, 2002). In line with such findings, one could hypothesize that pharmacologically increasing DA would influence attentional control during reading. Nevertheless, research has shown that the influence of increased DA levels in the brain on cognitive processes could be both positive and negative, based on the baseline level of DA in the brain. This model is called the inverted U-shape theory (Vijayraghavan et al., 2007) and states that both too low and too high levels of DA in the brain could hinder cognitive performance.

Next to the role of DA in attention control, DA is also involved in information-processing and memory formation (see e.g., Adcock et al., 2006; Boulougouris & Tsaltas, 2008; Braver & Cohen, 2000; Gazzaley & Rosen, 2016; González-Burgos & Feria-Valesco, 2008; Grossman et al., 2001; Kischka et al., 1996; Nieoullon, 2002). Studies have shown that psychopharmacological manipulations of DA levels have led to differing effects on memory performance across different learning tasks (e.g., artificial grammar learning tasks, word learning tasks) and different types of instruction (learning tasks with or without feedback; see Breitenstein, Floël, et al., 2006; de Vries et al., 2010; Knecht et al., 2004; Linssen et al., 2014). Wadley described DA as functioning as a "teaching signal," like a coach who tells his player "good job" or "bad job" to encourage future behaviour (2015, para. 10; see also Hamid et al., 2015). In this dissertation we examine whether higher DA levels in the brain during reading were beneficial for reading comprehension in a group of students carrying the DRD4 7-repeat allele and a group of students not carrying the DRD4 7-repeat allele, thereby testing the inverted U-shape theory in the case of reading comprehension.

The Role of Feedback in Supporting Reading Comprehension

In Chapters 4 and 5 of the dissertation, we shift our attention from the role of internal factors (i.e., attentional and dopaminergic processes) in reading comprehension, to the role of external factors in reading comprehension, most specifically, the role of feedback in reading comprehension. In Chapter 4, we investigate when and how to effectively provide feedback to students in order to support reading comprehension, and in Chapter 5, we examine the effects of feedback on cognitive processes (i.e., the use of reading strategies) and affective processes (i.e., motivational aspects) related to reading comprehension.

One of the hallmarks of excellent teachers is their ability to provide students with feedback (Hattie, 2012). Feedback is a vital element of reading comprehension instruction, together with deliberate practice and strategy instruction (see Crossley & McNamara, 2017). However, providing individualized feedback is a time consuming activity, time that often is not available to teachers and educational professionals. Technological innovations provide promising solutions. For example, computer applications provide a wealth of possibilities for providing individualized feedback to students during reading instruction.

Although decades of research have demonstrated that, on average, the effects of feedback on learning are positive (Azevedo & Bernard, 1995; Hattie, 2012; Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Kulhavy, 1977; Shute, 2008; van der Kleij et al., 2012, 2015), there also has been a great deal of variability in results across studies. For example, although the majority of studies have yielded positive effects, some have produced no effect, or even negative effects. Additionally, although several meta-analyses have been performed on the effects of feedback on learning (see Hattie, 2012), the combination of a broad range of study designs and learning tasks in these meta-analyses raise questions about the validity of applying the results to the specific case of reading comprehension (see also Bergeron & Rivard, 2017). Therefore, in the present dissertation we synthesize studies that specifically investigated the effects of feedback on reading comprehension in the context of learning from text.

Two main issues in research on the effects of feedback on learning are: (1) the timing of feedback (i.e., immediate feedback or feedback that is provided some hours or days after the task; see Dempsey & Wager, 1988; Hattie & Timperley, 2007; Metcalfe et al., 2009; Mory, 2004) and (2) the richness of feedback (i.e., the amount of information provided in feedback messages; see Shute, 2008). Both issues are addressed in Chapter 4 of the dissertation. With respect to timing, we further specify immediate feedback by distinguishing feedback that is provided during reading a text from feedback that is provided after reading a text. While previous research has categorized both of these moments as immediate feedback, these two moments have different consequences for the process of integrating information in the text and in the feedback messages in the mental representation of the text that readers have to form while reading (Bangert-Drowns et al., 1991; Mullet & Marsh, 2016; Subrahmanyam et al., 2013; see Chapter 4 for a more extensive review of the different perspectives on timing of feedback).

In addition to the issue of timing, we investigate the effects of the richness of feedback included in the feedback message on reading comprehension. The “richness” of a feedback message refers to the type of information included in the feedback message. Information can range from merely stating that an answer was right or wrong, to presenting the correct answer with explaining information (see e.g., Kulhavy, 1977; Shute, 2008). Research examining the effects of richness of feedback on the reading comprehension is sparse. Furthermore, results from decades of research on feedback in learning more generally has been inconclusive about the amount of information that should be provided in a feedback message in order to optimally support learning (see Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Kulhavy, 1977; Kulhavy & Stock, 1989, Mory, 2004; Shute, 2008; van der Kleij et al., 2015).

Although insight into the effects of different features of feedback is important for developing instructional tools, gaining a thorough understanding of the effectiveness of feedback requires investigation of how feedback fosters reading comprehension. As Kluger and DeNisi (1996) stated in their *Feedback Intervention Theory* (FIT), researchers should investigate students’ total reaction to feedback, not only the effect of feedback on the targeted learning outcome. In Chapter 5, we aimed to gain insight into students’ total reaction to feedback by testing the effects of feedback on both cognitive processes (i.e., the use of reading strategies) and affective processes (i.e., motivational aspects) related to reading comprehension.

An underlying cognitive process that has shown to be essential for reading comprehension is the use of reading strategies. When students are not able to effectively deploy reading strategies, for example, monitoring comprehension, questioning, rereading passages, and making inferences, their reading comprehension is negatively affected (see Gersten et al., 2001; Graesser, 2007; Palinscar & Brown, 1984). Therefore, researchers have stressed the importance of instruction in reading strategies to enhance reading comprehension, both for readers with and without difficulties in reading (see e.g., Crossley & McNamara, 2017; Edmonds et al., 2009; Gersten et al., 2001; National Reading Panel, 2000; Okkinga et al., 2018; Rosenshine & Meister, 1994). To enhance reading comprehension, feedback should help readers to develop or deploy (meta)cognitive strategies that are essential for reading comprehension by shifting their attention from performance (i.e., the product of reading comprehension) to learning itself (i.e., the processes needed to accomplish comprehension; see Hoska, 1993).

Next to supporting cognitive processes related to reading comprehension, such as the use of reading strategies, feedback could also play a role in affective processes related to reading, such as motivation. A diverse range of instructional practices has been shown to influence motivation for reading and reading engagement, which are both related to reading comprehension (see Guthrie et al., 2012; Guthrie & Wigfield, 2000; van Steensel et al., 2016). In line herewith, Hattie and Timperley (2007) in their extensive review on the impact of feedback concluded that feedback can function as a motivator for students (see also Kulhavy & Wager, 1993; ter Beek et al., 2018). The information provided in the feedback could provide students with feelings of autonomy and competence (Ryan & Deci, 2000) and might motivate them to increase cognitive effort, or engagement in the reading task (Kluger & DeNisi, 1996).

Aims and Outline of the Dissertation

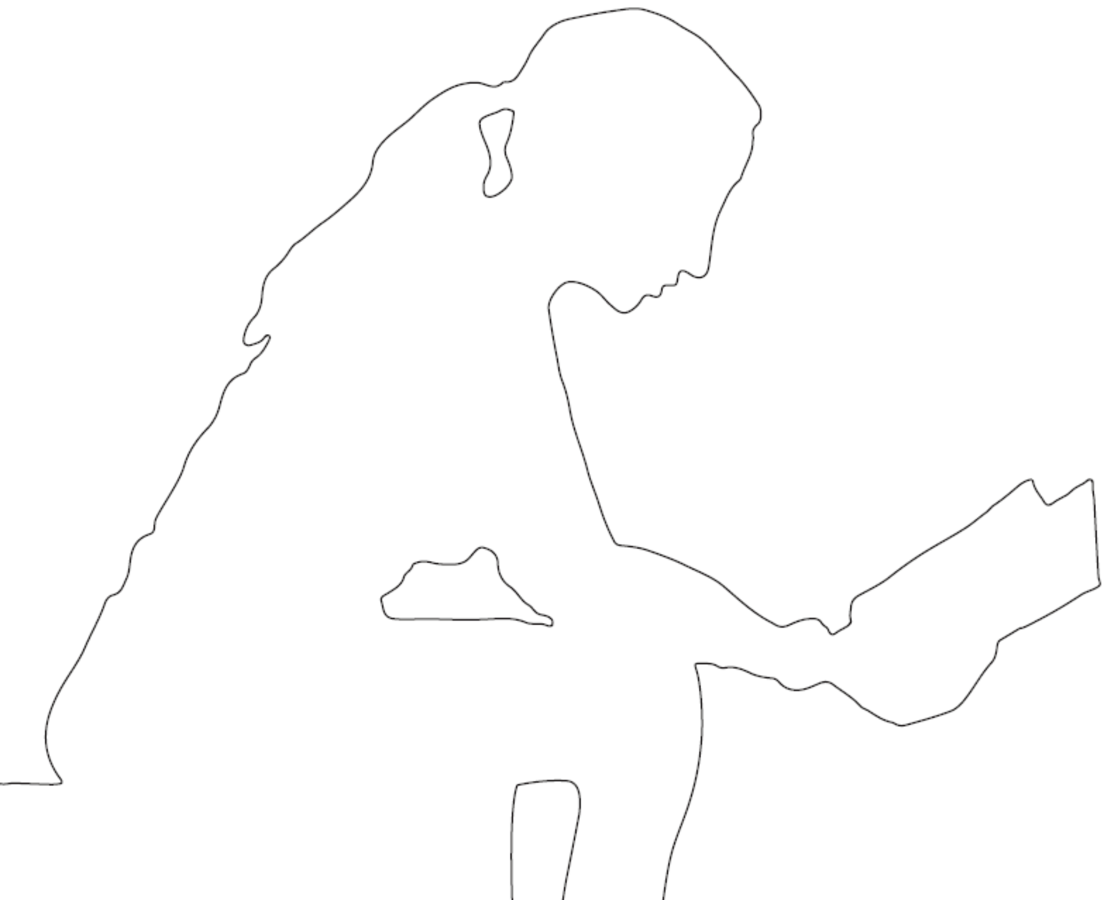
The aim of the present dissertation is to gain insight into both individual difference in reading and the effectiveness of instructional methods by investigating the role of internal and external factors related to reading comprehension. Using a multifaceted and methodologically diverse approach, two major themes are considered: (1) attentional and dopaminergic processes related to reading comprehension (i.e., internal factors) and (2) the effects of feedback (i.e., an external factor) on reading comprehension and on the processes underlying reading comprehension.

In **Chapter 2**, the potential use of frontal theta/beta-ratio (TBR) as a biomarker for attentional control is examined, and previous research on the relation between attention during reading and reading comprehension is replicated. We added to the existing literature by using frontal TBR as biomarker for attentional control in addition to self-report measures that are more commonly used. More specifically, the research reported in Chapter 2 investigates the potential of frontal TBR as a biomarker for attentional control in an EEG-study in which students read two narrative texts differing in text difficulty, self-report on attentional control during reading and in daily life, and then complete a measure of reading comprehension. The use of frontal TBR as indicator for attentional control during reading could provide greater insight into the role of attentional control during reading and its relation to reading comprehension because it is a more objective measure of attentional control that does not interrupt the natural reading process.

In **Chapter 3**, the influence of small increases in dopamine on attentional control during reading and reading performance is investigated in two groups of students: one group carrying the DRD4 7-repeat allele and one group not carrying the DRD4 7-repeat allele. In a double blind placebo-controlled experiment, we investigate participants' attentional control during reading and comprehension in two conditions: one in which levodopa, a precursor of dopamine in the brain, is administered before reading, and one in which a placebo is administered.

The main theme of **Chapters 4 and 5** is the effect of feedback on reading comprehension and on the cognitive and affective processes that are related to reading comprehension. These two chapters are based on meta-analytical research of more than six decades of research on the effects of feedback on reading comprehension. In **Chapter 4,** the effects of different features of feedback are investigated to gain insight into how best to support reading comprehension in the context of learning from text. Specifically, in this chapter, the effects of timing of feedback and the richness of feedback are investigated as moderators of the effect of feedback on reading comprehension. The aim of **Chapter 5** is to further unravel the effect of feedback on reading comprehension by testing the effects of feedback on cognitive and affective processes related to reading comprehension. The effect of feedback on the use of reading strategies when reading new texts without receiving feedback was investigated, as well as the effects of feedback on motivational aspects related to reading comprehension. Subsequently, it was tested if these effects could be used to predict the size of the effect of feedback on reading comprehension.

Finally, in **Chapter 6**, a summary and critical reflection on the results of this dissertation are presented, accompanied by implications of the results and suggestions for future research.



Chapter 2

Frontal Theta/Beta-Ratio (TBR) as Potential Biomarker for Attentional Control During Reading in Healthy Females

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Abstract

The aim of the present study was to expand previous research on the value of frontal theta/beta-ratio as a state measure of attentional control, by applying this measure during reading. Healthy female undergraduate students (N = 24) read two texts (with and without nonsense words), self-reported mind wandering during reading and filled in questionnaires about attentional control in daily life. Frontal theta/beta-ratios during the baseline phase and during reading were strongly related. The average frontal theta/beta-ratio during reading predicted reading comprehension of the text with nonsense words and fully mediated the relationship between frontal theta/beta-ratio during the baseline and reading comprehension. Fluctuations in frontal theta/beta-ratio during reading were related to frontal theta/beta-ratio during baseline and to self-reported mind wandering during reading for the text with nonsense words. Results show that frontal theta/beta-ratio is a promising state measure of attentional control during reading. Replication in other samples and with different texts is needed to better understand its potential.

Keywords: attentional control, mind wandering, reading comprehension, EEG, theta/beta ratio (TBR)

Introduction

The ability to accurately read and understand texts is indispensable for academic success. Students are expected to use reading as a tool for subject learning, such as history, chemistry, and foreign language learning. The grammar of these academic texts is complex and information density is high, requiring deep reading to comprehend these texts (LaRusso et al., 2016). In addition to decoding and language comprehension skills (Gough & Tunmer, 1986), deep reading requires the reader to regulate attention in order to continuously select and process information from the text (Arrington et al., 2014; Georgiou & Das, 2016). Research has shown that readers who better regulate their attention during reading have a better understanding of what they have read (Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Reichle et al., 2010; Sanders et al., 2017; Smallwood et al., 2007; Smallwood et al., 2008).

Measuring Attentional Control During Reading

Attentional control during reading is a difficult construct to measure. That is, there is no button that researchers can use to turn attentional control on and off while reading. As a consequence, most research on attentional control during reading uses indirect measures, like self-reports (see also Smallwood & Schooler, 2015). In these studies, participants are asked to report (the frequency of) moments where they failed to control attention, referred to as mind wandering. During mind wandering attention drifts away towards thoughts and feelings that are not relevant to the primary task someone is involved in (Smallwood & Schooler, 2006). During mind wandering people process information in a text they are reading at most on a superficial level (see Reichle et al., 2010; Smallwood, 2011). In studies on mind wandering during reading, probe-questions are most commonly used as a self-report measure. Several times during reading people are asked whether or not they are mind wandering (i.e., if they were experiencing lapses in attentional control). Other methods are asking participants to press a button during reading each time they realize that they are mind wandering (see e.g., Sanders et al., 2017) or retrospectively asking them to report on their attention during reading. Although the number of lapses in attentional control can be informative as an approximation of attentional control, reducing attentional control back to a dichotomous construct (i.e., treating attention as an all-or-none fashion) is an oversimplification. Attention can be controlled both consciously and unconsciously (see e.g., Golchert et al., 2017) and attention to a task can be coupled or decoupled in a hierarchically graded manner (Schad et al., 2012). This means that a reader can gradually lose attention, ranging from low-level decoupling of attention that mainly hinders deep-level processing of information in the text to high-level decoupling level of attention that hinders the reader from deep-level processing and superficial and perceptual level.

Drawbacks of Self-Reports of Lapses in Attentional Control

In addition to the fact that self-reports of mind wandering reduce attentional control to a dichotomous construct, the validity of self-reports as measure for attentional control during reading can be questioned. First, in most studies, texts are presented to participants sentence-by-sentence (e.g., Feng et al., 2013) or word-by-word (e.g., Smallwood et al., 2008), allowing the readers' eyes to only move forward in the text. However, research has shown that readers often fixate more than once on the same word, that 10 to 15% of the eye movements of skilled readers are regressions backward in text (Rayner et al., 2005). The number of regressions are even higher in the case of comprehension difficulties while reading a text (see also Ehrlich et al., 1999). Second, the use of probe questions forces the reader to interrupt reading several times to reflect on his or her mental state to answer the questions with regard to mind wandering. These interruptions may interfere with the construction of a mental model of the text – a representation of the meaning of the text in memory (van den Broek & Gustafson, 1999).

A third drawback of using self-reports arises from the discrepancy between unconscious and conscious moments of mind wandering (see Schooler et al., 2004; Seli et al., 2016). People are not always conscious of the fact that they are mind wandering (Smallwood & Schooler, 2006). Although unconscious moments of mind wandering are considered more detrimental to reading comprehension (Smallwood et al., 2008), these moments may be more difficult to assess using self-reports than conscious moments of mind wandering (Schooler, 2002).

A fourth drawback concerns the content-driven perspective of self-reports of mind wandering. Self-reports reveal something about the content of the readers' thoughts (see Faber & D'Mello, 2018; McVay & Kane, 2010; Smallwood & Schooler, 2006, 2015), but do not provide any information about the underlying processes in the brain (Christoff et al., 2016). Smallwood and Schooler (2006) argued that mind wandering can be seen as a redirection of executive, or attentional, control from the current task to more prominent personal goals and beliefs. According to this reasoning, mind wandering shares the same executive resources as task-related thinking. However, in McVay and Kane's *control failure x concerns* theory (2010) it is stated that mind wandering represents a failure, instead of a redirection, of attentional control to suppress task-unrelated thoughts. They describe task-unrelated thoughts as personal-goal-related thoughts that are continuously and automatically generated by the resting state or default network (DN) in the brain. The executive-control, or attentional control, system needs to prevent task-unrelated thoughts from inferring task-performance. In line with this reasoning, fMRI research showed that lapses in attentional control are related to increased activation in the DN and decreased activation in the frontal brain regions related to attentional control (Moss et al., 2013; Weissman et al., 2007).

The Potential of Using EEG to Measure Attentional Control

One potential method that might add to information obtained by self-reports of mind wandering as an indicator of attentional control would be the use of a biophysiological measure of attentional control during reading. Electroencephalography (EEG) might be a suitable method because it provides an "online" non-invasive measure of brain responses with good temporal resolution. That is, EEG does not interrupt the natural reading process and for capturing lapses in attentional control the reader is not required to be aware of mind wandering. Additionally, a continuous EEG measure is more in line with recent graded views of attentional control (see Schad et al., 2012). Also, combining different types of measures (e.g., EEG and self-reports) might help to expand our understanding of the construct. That is, EEG might help to better understand the processes that occur in the brain during self-reported mind wandering. Taking these considerations into account, in the present study we aim to use EEG technology to test a biophysiological marker of attentional control.

A large base of EEG research on attentional control processes has focused on brain activity in the alpha frequency band (for reviews see Bazanova & Vernon, 2014; Klimesch, 2012; Klimesch et al., 2007). However, research did not result in agreement about what specific index should be used as an indicator for attentional control and results show a mixed picture of the meaning of increases and decreases of alpha activity and its relation to attentional control. Alternatively, EEG-studies into the neural correlates of attentional control have shown that the ratio between slow waves (theta band; 4-7 Hz) and fast waves (beta band; 13-30 Hz) of frontal brain activity, the frontal theta/beta ratio (TBR), can be used as a biophysiological marker for attentional control with higher ratios reflecting lower levels of attentional control and lower ratios reflecting higher levels of attentional control (Aldemir et al., 2017; Angelidis et al., 2016; Barry et al., 2003; Putman et al., 2010, 2014; van Son et al., 2018). For example, children and adolescents with ADHD have higher frontal TBRs in resting conditions compared to typically developing individuals (for a review see Arns et al., 2011). In non-clinical samples, results are more nuanced. In some studies frontal TBRs during resting conditions were positively related to self-reports of attentional control in daily life (e.g., Angelidis et al., 2016; Putman et al., 2010, 2014). Other studies failed to find this relation (Angelidis et al., 2018; van Son et al., 2019a, 2019b). The samples and methodologies used in these non-clinical studies were comparable, except for the type of resting conditions during which EEG was recorded. In two out of three studies in which no relation was found (van Son et al., 2019a, 2019b), EEG was recorded in an eye-closed resting condition, while the previous studies that did find a relation (Angelidis et al., 2016; Putman et al., 2010, 2014) used a combined score for eyes-open and eyes-closed resting condition. Nevertheless, researchers could not explain if this difference in resting conditions could account for the difference in results and stated that replication was needed to clarify the relation between frontal TBR during resting conditions and self-reported attentional control in daily life.

Besides relating frontal TBR during resting states to trait attentional control, some researchers investigated fluctuations in frontal TBR during task performance in relation to state attentional control (Braboszcz & Delorme, 2011; van Son et al., 2019a). Whereas a trait measure is used as an indicator of attentional control in general, a state measure of attentional control should be sensitive to capture meaningful differences, or fluctuations, in attentional control that are influenced by situational circumstances and/or interactions between the person and the situation at a given time point (see also George, 1991). In line with this reasoning, Braboszcz and Delorme (2011) and Van Son et al. (2019a) found increasing frontal theta activity and decreasing frontal beta activity, resulting in an increase in frontal TBR, during periods of self-reported mind wandering compared to on-task periods in a breath-counting task. To the best of our knowledge, the present study is the first in which frontal TBR is investigated as an indicator of state attentional control during reading, which is a more complex cognitive task.

Present Study

The aim of the present study was twofold. On the one hand, we aimed to expand previous research investigating frontal TBR in relation to state attentional control (Braboszcz & Delorme, 2011; van Son et al., 2019a), during reading. On the other hand, we tested whether findings from previous studies, showing that attentional control during reading predicts reading comprehension (i.e., Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Reichle et al., 2010; Sanders et al., 2017; Smallwood et al., 2007, 2008), could be replicated when using frontal TBR as an indicator of state attentional control instead of self-report measures.

Frontal TBR as Indicator for Attentional Control During Reading

In order to fulfil the first aim of the study, expanding previous research on frontal TBR and attentional control to the field of reading, we tested the following four hypotheses:

Hypothesis 1. *The average frontal TBR during reading (as indicator of state attentional control) is related to frontal TBR during a baseline period and a self-report measure of attentional control in daily life.*

In line with previous studies showing strong correlations between scores on trait and state measures of the same ability or characteristic, for example in the case of mindfulness, anxiety and self-esteem, we expected a positive relation between the average frontal TBR during reading, which might be an indicator of state attentional control, and the self-report measure of attentional control in daily life, which reflects trait attentional control (Alessandri et al., 2016; Bertrams et al., 2010; Tsafou et al., 2017). Because frontal TBR during reading might be related to attentional control in daily life (see Angelidis et al., 2016; Putman et al., 2010, 2014), we also expected to find a relation between frontal TBR during reading and during the baseline.

Hypothesis 2. *Frontal TBR during reading differs across text conditions.*

The texts in the current study were read in two conditions that differed in difficulty level (i.e., with and without nonsense words). Research on mind wandering has shown that the frequency of self-reported mind wandering, or lapses in attentional control, increases with text difficulty (Feng et al., 2013; Forrin et al., 2017; Soemer & Schiefele, 2019). In line with this reasoning, we expected lower average attentional control during reading, in the text condition with nonsense words compared to the text condition without nonsense words which might be indicated by the average frontal TBR during reading to be higher.

Hypothesis 3. *Fluctuations in frontal TBR during reading are related to higher frequencies of self-reported mind wandering.*

In line with McVay and Kane's (2010) *control failure x concerns* theory of mind wandering, we expected that the frequency of self-reported mind wandering (reflecting lapses in attentional control) might be related to fluctuations in frontal TBR during reading. Another possibility, however, is that frequencies of self-reported mind wandering and fluctuations in frontal TBR are only weakly correlated because the sensitivity of self-report measures may suffer from the fact that the natural reading process is hindered and that unconscious lapses in attentional control cannot be self-reported (Seli et al., 2016).

Hypothesis 4. *The degree of fluctuations on frontal TBR during reading (i.e., SD in frontal TBR among text pages) is related to frontal TBR during the baseline.*

In line with research on sustained attention, in which fluctuations in reaction times to stimuli are used as indicators of attentional stability (for a review see Fortenbauch et al., 2017), we expected that students who are better at regulating their attention as might be indicated by lower baseline frontal TBR (as indicated by lower average scores) show more stable levels of frontal TBR (as indicated by smaller *SDs*) during reading .

Attentional Control as Predictor of Reading Comprehension

In order to fulfil the second aim of the study, replicating previous research showing that attentional control during reading predicts reading comprehension and provided that frontal TBR is related to attentional control, two hypotheses were tested:

Hypothesis 5. *The average frontal TBR during reading and/or fluctuations in frontal TBR during reading predict reading comprehension of the text.*

In line with the literature on attention and reading comprehension (Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Reichle et al., 2010; Sanders et al., 2017; Smallwood et al., 2007, 2008) we expected a negative relation between the average frontal TBR or fluctuations in frontal TBR during reading and reading comprehension, indicating that better attentional control is related to better reading comprehension. If so, this would support the predictive validity of frontal TBR as a state measure of attentional control. Additionally, previous research on mind wandering and reading comprehension showed that mind wandering is not only reported more often but also particularly detrimental for reading comprehension in the case of difficult texts (Feng et al., 2013; Forrin et al., 2017; Smallwood & Schooler, 2006; Soemer & Schiefele, 2019). In line herewith, relations between frontal TBR or fluctuations on frontal TBR during reading and reading comprehension might be stronger for the text with nonsense words, i.e., the more difficult text.

Hypothesis 6. *The relation between the participants' frontal TBR during the baseline period and reading comprehension could be mediated by the relation between participants' (1) frontal TBR during reading or (2) fluctuations in frontal TBR during reading (i.e., possible indicators of state attentional control) and reading comprehension.*

As George (1991) argued, the added value of a state measure compared to a trait measure is the higher sensitivity to meaningful fluctuations influenced by situational circumstances or interactions between the person and the specific situation or activity (i.e., reading a text that is more or less difficult). In the case of frontal TBR as an indicator of attentional control, we expected that frontal TBR during the baseline period is related to frontal TBR or fluctuations in frontal TBR during reading, but that the relation between frontal TBR during the baseline period and reading comprehension is only indirect, through an effect of frontal TBR or fluctuations in frontal TBR during reading on reading comprehension. A similar mediation effect was recently found for trait mindfulness, state mindfulness and physical activity (Tsafou et al., 2017).

Materials and Methods

Participants

Participants were 28 healthy first-year female students in Social Sciences from a Dutch university, who voluntarily signed up for participation. Participants were between 18 and 29 years old (*M* = 19.29, *SD* = 2.24). Because of the large proportion of female students within the faculty, it was decided to include only female participants. Participants could only participate if they were right-handed native Dutch speakers without learning disabilities and had good or corrected vision. Participants were not permitted to use drugs or medication (with the exception of contraceptives) two weeks prior to the experiment. Students were recruited through advertisement on the university website and signed an informed consent prior to participating. Students received research participation credits that they could use for their study. During the experiment four students reported that they were familiar with the novel from which the texts in the study were derived. These students were excluded resulting in a final sample of 24 students (*M* = 19.29 years, *SD* = 2.24).

Research Design

A within-subjects experimental design with two text conditions differing in difficulty was executed: (1) text with nonsense words versus (2) text without nonsense words. Two comparable texts (A and B) were used in each condition, resulting in four possible combinations of text order (A and B) and conditions (with or without nonsense words), which were randomly assigned to each participant. The combination of a within-subjects design and the random assignment of text order and condition to each participant prevents possible biases, as a consequence of text order, fatigue or differences between the text A and B, to influence the results of the study.

Procedure

The procedures in the present study were approved by the ethics committee of the department of Education and Child Studies.

First Session

The first session, lasting approximately one and a half hour, took place in the EEG-lab at the university. An EEG sensor net was first placed on the head of the participant. Subsequently, two three-minutes baseline measures were recorded: one with the eyes closed and one with the eyes open. Next, the concept *mind wandering* was explained to the participant. In line with the definition of mind wandering used in previous research (for a review see Smallwood & Schooler, 2015), the following instruction was provided: “Mind wandering is used to indicate what happens if your attention is distracted from a task. You may be thinking of personal things or worries instead of reading the text. In other cases you become distracted because you are tired or bored. You are not consciously thinking about something else; you only know that you are not focused on the content of the text. Everyone mind wanders sometimes, especially during longer tasks as reading a text.” After the explanation, participants read one of the two texts either with or without nonsense words. Texts were presented on a computer screen. In order to assess attentional control during reading, at eight fixed points in the text, randomly chosen by the researcher (after every 2-5 pages), a question appeared on the screen asking whether the participant was mind wandering or not. After the student finished reading the text, reading comprehension was measured using a recall task in which the participants had to write a one-page summary of the text they read. After a five-minute break in which the signal of the electrodes in the EEG-net was checked, the same procedure was followed with the second text.

Second Session

A second session, taking place in a quiet laboratory room at the university, was planned within two weeks after the first one. Participants completed the Attentional Control Scale and the BRIEF-A, measuring attentional control in daily life.

Materials

The target texts were two passages of respectively 2,524 and 2,545 words from a Dutch translation of the novel “A Clockwork Orange” (Burgess, 1962/2012). The passages were taken from two separate chapters and were understandable without knowing the rest of the storyline. Events in the two chapters did not necessarily have to take place in the order they appeared in the book, which made counterbalancing of the order of the two texts possible. Although the book contains multiple highly violent passages, the texts used in the present study did not include excerpts of these violent passages. The original texts included nonsense words from a fictional language, referred to as Nadsat, that was used by some of the characters in the book (e.g., ‘wesjes’ for *things* and ‘kopatten’ for *understanding*; for a dictionary of the English version of the Nadsat language used in the book, see www.nadsatdictionary.com). Text A included 122 nonsense words (4.8% of the total number of words), text B included 136 nonsense words (5.3% of the total number of words). Two conditions were created for each of the two passages, a difficult condition that included the nonsense words and an easier condition in which the nonsense words were replaced by their regular Dutch meaning. The texts were presented on a computer screen in paragraphs of approximately 100 words. Participants could only move forward in the text.

Measurement Instruments

Two self-report measures were used to assess attentional control in daily life: (1) Attentional Control Scale (Derryberry & Reed, 2002), and (2) BRIEF-A (Scholte & Noens, 2011).

Attentional Control Scale (ACS)

Participants rated twenty statements about attention and concentration in daily life on a four-point Likert-scale (e.g., ‘It’s very hard for me to concentrate on a difficult task when there are noises around’ and ‘After being disrupted or distracted, it is easy for me to shift my attention away from the distractor’). Sum scores on the two subscales of the ASC, focused attention and attentional shifting, were calculated. The subscale focused attention consisted of nine items, with a sum score ranging from 9 to 36 points. Internal consistency was Cronbach’s $\alpha = .61$. The subscale attentional shifting consisted of eleven items, with a sum score ranging from 11 to 44 points. Internal consistency was Cronbach’s $\alpha = .62$.

BRIEF-A

Participants rated the frequency of behaviours and thoughts on a 3-point Likert-scale. The self-report questionnaire consisted of 75 items on executive functioning in daily life. In the present study we used the Cognitive Flexibility subscale of the BRIEF-A because this subscale measures attentional shifting among tasks and thoughts. The subscale consisted of 6 items (e.g., 'I have trouble making the transition from one task or activity to another', or' I get upset from sudden changes in my daily routines'). A total score was calculated for each participant, ranging from 6 to 18 points, with a higher score reflecting better attentional shifting. Internal consistency of the scale was Cronbach's α = .58, which was regarded acceptable considering the low number of items (Field, 2013).

Aggregate Score for Attentional Control in Daily Life

In order to reduce the number of variables and to prevent that multicollinearity among the self-reports may cause problems in further analyses, the subscales focused attention and attentional shifting (ACS) and cognitive flexibility (BRIEF-A) were combined into one aggregate measure for attentional control in daily life. Principal component analysis applied to the three subscales resulted in one component, containing component loadings ranging from .73 to .89, explaining 67.8% of the variance. Scores were combined by calculating the average standardized score, with a higher score reflecting better attentional control.

Frontal TBR

EEG data were recorded during a baseline period and during reading. We used 129-channel hydrocel Geodesic sensor nets and electrodes were placed according to the 10-20 system amplified by a NetAmps300 amplifier at a digitization rate of 500Hz (Electrical Geodesics Inc.). Impedances were kept below 50 kΩ. Raw data were further processed offline using Brain Vision Analyzer 2.0 software (Brain Products). Data were low-pass filtered at 100 Hz (-3 dB, 48 dB/oct) and high-pass filtered at 0.3 Hz (99.9% pass-band gain, 0.1% stop-band gain, 1.5 Hz roll-off) with a notch-filter of 50 Hz to eliminate electrical noise. Subsequently, EEG data were referenced to the average activity in all channels and ocular correction was performed using the Gratton and Coles' procedure (Gratton et al., 1983). To retain as much artefact-free data as possible, raw EEG data were segmented in 2-second segments with an overlap of 5%. Segments containing artefacts (defined as: voltage steps exceeding 50 μV/ms, differences in values above 100 μV within an interval of 200 ms, amplitudes lower than -70 μV or higher than 70 μV or segments containing less than 0.5 μV activity in intervals of 100 ms intervals) were excluded from further analyses. In addition, noisy channels were replaced by average activity of the closest electrodes. After segmenting the data and correcting for artefacts, power densities in the theta (4-7 Hz) and beta (13-30 Hz) frequency bands were calculated with a fast Fourier transformation (resolution 0.25 Hz, hamming window 10%). Frontal TBR was calculated for the two three-minutes baseline periods and for each text page, based on the average power density of three frontal electrodes (F3, Fz and F4, represented by electrode numbers 24, 11, and 124 respectively; Putman et al., 2010, 2014). Because of non-normality, power density values within each frequency band were log-normalized before calculating the ratios. The average frontal TBR during the baseline was calculated by averaging frontal TBR for both baseline periods (i.e., eyes closed and eyes open). The average frontal TBR during reading was calculated by averaging frontal TBR for all text pages within each text condition (with and without nonsense words). Higher ratios reflected lower attentional control. Additionally, the standard deviation of frontal TBR among all text pages was also calculated for both text conditions, indicating the level of fluctuations in frontal TBR during reading.

Self-Reported Mind Wandering

Reading passages were interrupted at eight random points with the question: "Were you mind wandering?". This probe appeared only at moments when participants pressed the button to go to the next page. Participants could answer the mind wandering question by indicating 'yes' or 'no'. The probes were presented within intervals of 2-5 pages (i.e., after 200-500 words). The frequency of self-reported mind wandering was used as an indicator of lapses in attentional control during reading.

Reading Comprehension

The one-page summaries participants wrote were coded based on a list of 12 main elements from text A and 15 elements from text B, constructed by the researchers, including the main characters (e.g., Alex is a boy who does a lot of things which are illegal), events in the text (e.g., Alex has a nightmare about violence), motives of characters (e.g., Alex will be obedient during his treatment because he hopes that he then will be liberated soon), and relations between events (e.g., Alex got a visit from his probation officer, because the officer had heard rumours about a fight in which Alex' name appeared). A percentage of correctly mentioned main elements for each summary was calculated. Two coders independently coded all summaries. Intercoder-reliability for all separate main elements in the summaries equalled *r* = .93 (intraclass correlation). Final scores were based on consensus after discussing disagreements.

Statistical Analyses and Data Reduction

Data on all outcome measures were complete for all participants (*N* = 24), except for the ACS (*n* = 22) which was not filled in by two participants. As a consequence, no aggregate scores for attentional control in daily life were available for these two participants. The variable *SD* in frontal TBR, which was calculated as an indicator of the amount of fluctuations in frontal TBR among the pages in each text condition (with and without nonsense words), included three outliers (*z*-score > 3) in the text condition with nonsense words. These scores were winsorized into .001 higher than the highest non-outlying value (Hampel et al., 1986). The rank order of scores was maintained by adding .001 to each next outlier. For *SD* in frontal TBR in the text condition without nonsense words, two outliers were winsorized.

Differences in scores between the two text conditions (with and without nonsense words) were tested using paired *t*-tests. In order to assess the strength and direction of an association between two variables we executed Pearson's product-moment correlations. Only reporting the *p*-value for an analysis is not adequate to fully understand the results as this value is not only dependent on the effect size but also on the sample size. Therefore, next to the significance level of the test statistics, we reported the effect sizes and the 95% confidence intervals of the effect sizes for all (paired) *t*-tests and correlational analyses (see Lancaster et al., 2002; Maxwell, 2004). Additionally, we decided to interpret alpha levels between .05 and .10 as marginally significant (see Gail et al., 2012; Noymer, 2011). Effect sizes for marginally significant and significant differences and correlations were interpreted based on Cohen's criteria (Cohen, 1992).

To test if the average frontal TBR or fluctuations in frontal TBR during reading would mediate the relation between the average frontal TBR during the baseline and reading comprehension, we performed mediation analyses following the steps proposed by Baron and Kenny (1986) and tested the significance of the mediation using Sobel's test.

Results

Descriptive Statistics

Participants tended to spend more time reading the text with nonsense words than the text without nonsense words (*t* (23) = -1.77, *p* = .09, *d* = 0.25, 95% CI = [-0.32, 0.82], paired *t*-test). Furthermore, participants reported mind wandering marginally significantly more often when reading the text with nonsense words than without nonsense words (t (23)= -1.95, p = .06, d = 0.39, 95% CI = [-0.18, 0.96], paired t-test), and recalled a marginally significantly greater number of main elements of the text without nonsense words than the text with nonsense words (t (23)= 2.07, p = .05, d = 0.54, 95% CI = [-0.04, 1.11], paired t-test). Descriptive statistics for the behavioural outcome measures in both text conditions are reported in Table 1. Although differences were marginally significant, taken together, the pattern of results for reading time, mind-wandering, and recall support the idea that the text with nonsense words was more difficult for participants to process than the text without nonsense words.

Frontal TBR During Reading, During the Baseline, and Attentional Control in Daily Life

Frontal TBR During Reading and During the Baseline

In line with what we expected according to hypothesis 1, the average frontal TBR during reading correlated strongly with frontal TBR during the baseline (M = 0.41, SD = 0.22). This was the case in both the text condition with nonsense words (M = 0.29, SD = 0.39, r = .69, p < .001, 95% CI = [.40, .85]) and the text condition without nonsense words (M = .0.26, SD = 0.29, r = .52, p < .001, 95% CI = [.15, .76], see Table 2).

Frontal TBR During Reading and Self-Reported Attentional Control in Daily Life

The average frontal TBR during reading in the text condition with nonsense words was marginally significantly related to self-reported attentional control in daily life (r = -.41, p = .06, 95% CI = [-.70, -.01]). Participants who reported to be better able to control their attention during daily life, had on average a lower average frontal TBR during reading, reflecting better attentional control during reading. However, the first hypothesis is only partly confirmed at this point. That is, the relation between frontal TBR during reading in the text condition without nonsense words and self-reported attentional control in daily life was not significant (r = -.26, p = .24, 95% CI = [-0.60, 0.16]).

Differences in Frontal TBR During Reading Between Text Conditions

Contrary to what was expected according to hypothesis 2, no difference was found between the average frontal TBR during reading in the text condition with nonsense words (M = 0.29, SD = 0.39) and the average frontal TBR during reading in the text without nonsense words (*M* = 0.26, *SD* = 0.29, $t(23) = 0.36$, $p = .72$, $d = -0.20$, 95% CI = [-0.77, 0.36]).

Fluctuations in Frontal TBR During Reading and Self-Reported Mind Wandering

In line with hypothesis 3, both in the text condition with nonsense words ($r = .37$, $p = .07$, 95% CI = [-.04, .67]) and the text condition without nonsense words ($r = .34$, $p = .10$, 95% CI = [-.07, .65]), standard deviations in frontal TBR among pages within a text were marginally significantly correlated with the self-reported frequency of mind wandering. In other words, students who showed a higher level of fluctuations in TBR among pages within a text tended to also report mind wandering more often during the text.

Fluctuations in Frontal TBR During Reading and Frontal TBR During the Baseline

Hypothesis 4 was confirmed for the text with nonsense words but not for the text without nonsense words. For the text condition with nonsense words, the relation between the average frontal TBR during the baseline and the standard deviation in frontal TBR among text pages was significant and strong ($r = -.52$, $p = .01$, 95% CI = [-.76, -.15], see Table 2). Students with lower average frontal TBR during the baseline showed more fluctuations in frontal TBR during reading. For the text condition without nonsense words, we found a similar pattern, however this relation was less strong and only marginally significant ($r = -.37$, $p = .08$, 95% CI = [-.67, .04]).

Frontal TBR During Reading or Fluctuations in Frontal TBR as Predictor for Reading Comprehension

For the text condition with nonsense words, a significant relation was found between the *average* frontal TBR during reading and reading comprehension ($r = -.56$, $p < .01$, 95% CI = [-.79, -.20]), a large effect (Cohen, 1992). A lower frontal TBR that might indicate better attentional control during reading, was related to a higher number of main elements recalled from the text after reading. This result is in line with hypothesis 5. Students who are on average better in controlling their attention during reading will score higher on reading comprehension. However, the fifth hypothesis was not completely confirmed as fluctuations in attentional control during reading were not related to reading comprehension of the text (r = .08, p = .71, 95% CI = [-.33, .47]). In the same vein, for the text condition without nonsense words, neither the *average* frontal TBR (r = -.04, p = .84, 95% CI = [-.44, .37]), nor the level of *fluctuations* in frontal TBR during reading (r = .07, p = .74, 95% CI = [-.34, .46]) were related to reading comprehension.

Frontal TBR During the Baseline, During Reading and Reading Comprehension

In line with hypothesis 6, for the text with nonsense words, mediation analysis showed a significant indirect effect of the average frontal TBR during the baseline on reading comprehension through the average frontal TBR during reading (see Figure 1; R^2 = .31, F(2, 21) = 4.82, p = .02, tolerance = .53, VIF = 1.90). In other words, attentional control during reading, for which the average frontal TBR during reading might be indicative, significantly mediated the relationship between the average frontal TBR during the baseline and reading comprehension (Sobel test = -1.97, SE = 13.46, p = .05). Because fluctuations in frontal TBR during reading were related to reading comprehension in neither of the text conditions, and the average frontal TBR was not related to reading comprehension in the text condition without nonsense words, no mediation analyses were performed for these variables.

Discussion

The first aim of the present study (see hypotheses 1 to 4) was to clarify the value of frontal TBR as a state measure of attentional control during reading. To explore the validity of frontal TBR as a state measure of attentional control, we related the average frontal TBR during reading to the average frontal TBR during the baseline and to attentional control in daily life as measured by self-report questionnaires. Frontal TBR during reading and during the baseline were strongly related. Frontal TBR during reading was marginally significantly and moderately related to attentional control in daily life, but frontal TBR during the baseline and during reading in the text condition without nonsense words were not related to attentional control in daily life. The strength of the correlation between frontal TBR in the text condition with nonsense words and attentional control in daily life was comparable to relations found in previous studies in which frontal TBR was measured during resting conditions and tested in relation to attentional control (Angelidis et al., 2016; Putman et al., 2010, 2014). No difference was found between the average frontal TBRs in the text conditions with and without nonsense words.

Participants who showed higher levels of fluctuations in frontal TBR during reading tended to report mind wandering more often. These relations were marginally significant with a moderate effect size in both text conditions. The relations between fluctuations in frontal TBR and mind wandering found in the current study are in line with results in the literature where differences in frontal TBR between periods of mind wandering and periods of on task behaviour using a cognitively less complex task were found (Braboszcz & Delorme, 2011; van Son et al., 2019a). Additionally, the relations between fluctuations in frontal TBR and the self-reported frequency of mind wandering support the *control failure x concerns* theory of mind wandering (McVay & Kane, 2010), stating that mind wandering is a consequence of a failure of the attentional control system to suppress task-irrelevant thoughts and feelings. If periods of mind wandering do not represent a failure of the attentional control system, but a redirection of attentional control which appeals to the same resources (see Smallwood & Schooler, 2006), one would expect the attentional control system to be equally active during reading as during mind wandering. Accordingly, no fluctuations in frontal TBR would be expected.

We also investigated the relations between frontal TBR during the baseline and the level of fluctuations in frontal TBR during reading. Contrary to what we expected (see hypothesis 4), lower levels of frontal TBR during the baseline, which were related to lower attentional control in previous studies (e.g., Aldemir et al., 2017; Angelidis et al., 2016; Putman et al., 2010, 2014; van Son et al., 2018), were related to a higher level of fluctuations in frontal TBR during reading. However, research has shown that people who show high levels of attentional control are also better in controlling mind wandering in accordance with the cognitive demands of the task (Golchert et al., 2017; Rummel & Boywitt, 2014). As a consequence, people who can better regulate their attention show less spontaneous or unconscious mind wandering, but report more often to deliberately mind wander during a task (Golchert et al., 2017). Therefore an alternative interpretation might be that fluctuations in frontal TBR may also represent the ability of a reader to maintain the balance between periods of fully focusing on the text and moments of mind wandering. That is, these participants might be better able to consciously controlling their attention, and, are able to bring their focus back on the text when necessary, for instance when reading parts of the text were information density is high or for sections that are more complex or where the presented information is central for understanding the text.

The second aim of the present study (see hypothesis 5 and 6) was to explore whether the relation between attentional control and reading comprehension found in previous studies (Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Reichle et al., 2010; Sanders et al., 2017; Smallwood et al., 2007, 2008), could be replicated when using frontal TBR during reading as a biomarker for state attentional control. A strong relation was found between frontal TBR during reading and reading comprehension for the text condition with nonsense words, but not for the text condition without nonsense words. Also, self-reported mind wandering was not related to reading comprehension. The discrepancy among the relation between frontal TBR during reading and reading comprehension found in the text condition with nonsense words but not in the text condition without nonsense words is in line with previous findings showing that failures in attentional control are particularly detrimental for comprehension of difficult texts (Feng et al., 2013). In other words, as expected, attentional control seems especially important for deep reading to understand complex texts (LaRusso et al., 2016). Additionally, we found that frontal TBR during reading (as indicator of state attentional control) fully mediated the relation between frontal TBR during the baseline and reading comprehension. Multicollinearity was not a problem in this mediation analysis (i.e., correlations between the predictors were below .80 and VIF was far below 5; see Craney & Surles, 2002; Pedhazur 1997), supporting the idea that state attentional control during reading can be measured separately from baseline attentional control using frontal TBR as a biophysiological marker. The mediation model shows us that attentional control in general is important, but that it only partially explains attentional control under specific circumstances, in the case of our study during reading a difficult text, and that especially attentional control during reading is an important predictor of reading comprehension. This emphasizes the importance of being able to monitor attentional control during reading in an ecologically valid way using a measure that is sensitive for fluctuations in attentional control without disturbing the reading process.

Despite the preliminary nature of the data and the low power, the results of the present study and the strong effect sizes in particular (up to r = 0.69; Cohen, 1992), do suggest that frontal TBR has potential as biophysiological marker for attentional control during reading. The advantage of EEG, compared to self-reports of mind wandering as indicator of lapses in attentional control, is that it measures brain potentials without interrupting the natural reading process. The fact that the presentation of text is not restricted to single words or sentences enhances ecological validity of the measurement instrument. Additionally, individual differences in frontal TBR during reading were related to self-reported attentional control in daily life and to reading outcomes in the text condition with nonsense words. Higher ratios, indicating less attentional control, were related to less attentional control in daily life and lower reading comprehension. The fact that relations between attentional control in daily life, attentional control during reading and reading comprehension were mainly present in the text condition with nonsense words is consistent with literature showing that attentional control is particularly important in executing complex tasks (Feng, et al., 2013; Golchert et al., 2017; Larusso et al., 2016). Besides that, frontal TBR seemed to be sensitive for fluctuations in attentional control, as appeared from the moderately strong, although marginally significantly, relations between fluctuations in frontal TBR and the self-reported frequency of mind wandering (i.e., lapses in attentional control). This might indicate that fluctuations in frontal TBR during reading reflect meaningful differences in attentional control (i.e., lapses in attentional control), which advocates for the suitability of frontal TBR as an indicator for state attentional control.

Limitations and Future Research

The present study is an exploratory study with a small sample resulting in low statistical power. Therefore, although the present study contains promising results and effect sizes, the present study should be replicated with larger and more diverse samples (e.g., boys, girls, readers with and without reading difficulties) to affirm the results. Considering the close relationship between executive functions like attentional control and intelligence (Jurado & Rosselli, 2007), future research should investigate frontal TBR during reading as a measure for attentional control during reading with other samples. Additionally, the texts used in this study were relatively short compared to texts used in previous studies on mind wandering (e.g., Dixon & Bortolussi, 2013; Feng et al., 2013; McVay & Kane, 2012; Reichle et al., 2010; Smallwood et al., 2008). Future research should also focus on the course of attentional control during reading longer texts and its influence on reading outcomes. Additionally, future research could focus on possible differences in brain activity underlying deliberate and spontaneous moments of mind wandering, to gain more insight in the relation between mind wandering and attentional control (see Golchert et al., 2017). In the present study, we were not able to distinguish between spontaneous and deliberate mind wandering. A promising approach to gain more insight in processes underlying lapses in attentional control is the combination of eye movements data (e.g., pupil size; Konishi et al., 2017; fixation duration; Reichle et al., 2010; within-word regressions; Uzzaman & Joordens, 2011; eye blinks; Smilek et al., 2010, see also Faber et al., 2018; Schad et al., 2012) and EEG-recordings. Both techniques are becoming more and more accessible due to the rapid technological innovations and methods for co-registration of eye-movements and EEG are becoming increasingly popular in studying cognitive processes in naturalistic settings (Nikolaev et al., 2016). Both methods can be used to further unravel the processes underlying attentional control without hindering the natural reading process (see also Dimigen et al., 2011).

Insight into the course of attentional control during reading could be a starting point for developing interventions and instruction methods that guide task-related attentional processes. For example, Sanders et al. (2017) found that explicitly instructing people to monitor their attention (i.e., being focused on detecting moments of mind wandering and refocus when mind wandering occurs) during reading resulted in less mind wandering, but this method had a negative effect on comprehension. Alternatively, instructing participants to focus on constructing a mental model during reading did not result in less mind wandering – as was indicated by the self-reported frequency of mind wandering – but did improve reading comprehension (Sanders et al., 2017). Encouraging results have been found in a study using a brain-computer interface to help readers control their attention during reading, demonstrating the usefulness of single-electrode EEG devices to monitor attention during reading and to remind the reader to stay focused when attention is fading (Chen & Huang, 2014).

Conclusion

The present study is, to the best of our knowledge, the first one in which attentional control during reading was assessed using frontal TBR. Results suggest that frontal TBR is a promising biophysiological marker for attentional control during reading as: (1) frontal TBR during reading a complex text was marginally significantly related to self-reports of attentional control in daily life, (2) frontal TBR during reading was strongly related to baseline frontal TBR, (3) fluctuations in frontal TBR were related to the frequency of self-reported mind wandering and to baseline frontal TBR, (4) frontal TBR during reading significantly predicted reading comprehension in a complex text, and (5) frontal TBR during reading mediated the relationship between baseline frontal TBR and reading comprehension in the complex text. Given the low power but promising effect sizes found in the present research, particularly in the complex text condition, replication of results with larger and more diverse samples and with different texts is needed before firm conclusions can be drawn.

Table 1

Descriptive Statistics for the Behavioural Outcome Measures in Both Text Conditions

		With nonsense words				Without nonsense words			
	N	Min.	Max.	*M*	*SD*	Min.	Max.	*M*	*SD*
Mind wandering (max. 8)[1]	24	0.00	7.00	3.71	2.01	0.00	6.00	3.00	1.62
Reading time (minutes)	24	6.28	15.62	10.64	2.58	7.35	15.35	10.05	2.14
Recall task (% correct)	24	0.00	60.00	25.56	15.69	13.30	53.30	32.78	10.93

Note. [1]The number of times participants reported to be mind wandering (i.e., responded 'yes' on the mind wandering questions).

Table 2

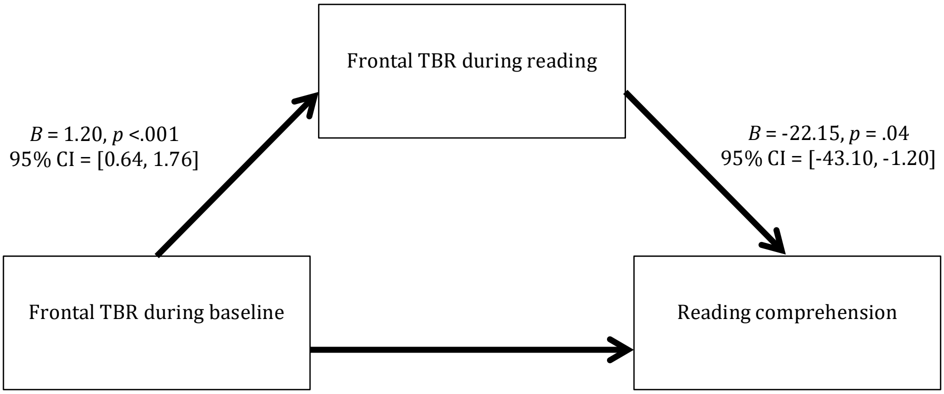
Correlations Among Frontal TBR and Other Outcome Measures

		Condition with nonsense words					Condition without nonsense words				
		1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
1.	Attentional control in daily life (factor score)	1					1				
2.	Frontal TBR during baseline[1]	-.35	1				-.35	1			
3.	Frontal TBR during reading[1]	-.41†	.69**	1			-.26	.52**	1		
4.	*SD* frontal TBR during reading	.34	-.52**	-.43*	1		.22	-.37†	-.75**	1	
5.	Self-reported mind wandering	-.32	-.26	-.08	.37†	1	-.12	-.36†	-.31	.34†	1
6.	Reading comprehension	.38	-.40†	-.56**	.08	-.16	.47*	-.22	-.04	.07	-.31

Note: [1]higher ratios represent lower levels of attentional control. † p <.10; * p <.05; ** p <.01

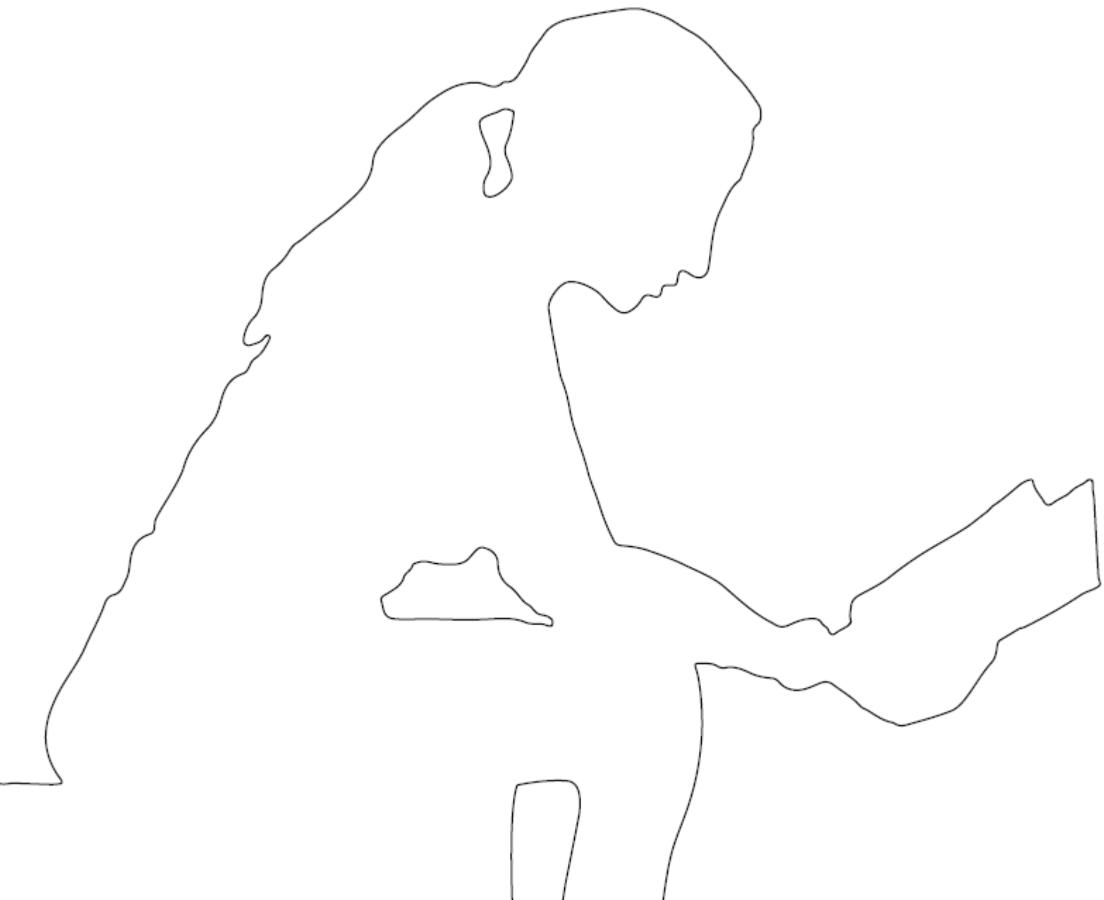
Figure 1:

Diagram Showing the Mediation Effect of Students' Attentional Control During Reading, as Might be Indicated by the Average Frontal TBR During Reading, for the Relation Between Average Frontal TBR During the Baseline and Reading Comprehension in the Text Condition With Nonsense Words.



Direct effect: B = -27.80, p = .06, 95% CI = [-56.33, 0.73]

Indirect effect: B = -1.27, p = .94, 95% CI = [-37.70, 35.16]



Chapter 3

The Effects of Increased Dopamine-Levels on Attentional Control During Reading and Reading Comprehension

Based on:

Swart, E. K., & Sikkema-de Jong, T. M. (under review). The effects of increased dopamine-levels on attentional control during reading and reading comprehension.

Abstract

The aim of the present study was to gain insight in the neurobiological processes, particularly the dopaminergic processes, underlying attentional control during reading and reading comprehension. In order to test the effects of increased dopamine (DA) in the brain, female university students *(N* = 80*),* half of them carrier the DRD4-7R allele and half of them not, participated in a double blind placebo-controlled within-subject experiment in which they were orally administered levodopa or a placebo before reading a text. After reading the text, participants reported on their attentional control during reading and completed comprehension questions. Pharmacologically increasing DA levels in the brain negatively influenced reading comprehension. This effect was moderate (η_p^2 = .13). Alternatively, increased DA levels in the brain did not affect attentional control. No interaction effects of condition and DRD4 genotype were found, for either attentional control or reading comprehension. Results are discussed from the perspective of the inverted U-shape theory and the possible dopamine-related mechanisms.

Keywords: dopamine, attentional control, reading comprehension, inverted U-shape theory

Note

This study was registered with EudraCT European Clinical Trials Database (Identifier: 2014-001352-36). We acknowledge dr. A. G. Bus for her input to the design of the study at the start of the project.

Introduction

Reading texts requires the reader to control attention for a longer period of time in order to encode and integrate the information into a coherent mental representation of the text (see e.g., van den Broek et al., 2005). This mental representation is constructed by extracting meaning from the text, and the quality of the mental representation is related to the ability of the reader to learn from texts (van den Broek et al., 2005). Research has shown that people who are better able to control their attention during reading learn more from the texts they read (e.g., Sanders et al., 2017; Zhou et al., 2020). Arrington et al. (2014) showed that attentional control, specifically the ability to sustain attention for a longer period of time, and the ability to prevent irrelevant thoughts or information from interfering with performing a task, had a direct positive effect on reading comprehension. Adolescents who were better able to regulate attention, scored higher on reading comprehension. Conners (2009) argued that attentional control should be seen as a third and fundamental component of reading comprehension, just as decades of research have shown for the two components of reading comprehension according to the Simple View of Reading (Gough & Tunmer, 1986). In line with Arrington et al. (2014) and Conners (2009) research on attentional control and reading comprehension, in the present study we defined attentional control as an umbrella construct referring to the allocation of attentional processes and resources, including inhibition of irrelevant and interfering information, selectivity of attention for task-relevant information and sustaining attention for longer periods of time.

Several lines of research have focused on training attentional control via action video games (Green & Bavelier, 2012), mindfulness and meditation (Chiesa et al., 2011), and cognitive training (e.g., Karbach & Verhaeghen, 2014). Results of the research have shown positive effects of training on performance on neuropsychological tasks demanding attentional control, yet few however have examined whether or not this improved performance transfers to other, real-world tasks (see Owen et al., 2010).

Specific to reading comprehension, the effects of attentional control training have varied. For example, Zanesco et al. (2016) found that mediation training improved attentional control during reading, yet the improved attentional control did not lead to improved reading comprehension. Sanders et al. (2017) found that instructing readers to monitor their attention during reading resulted in better attentional control during reading, but negatively influenced reading comprehension, whereas instructing readers to focus on the construction of a mental representation of the text resulted in improved reading comprehension, but had no effect on attentional control. Finally, Mrazek et al. (2013) found positive effects of a mindfulness training on both attentional control during reading and reading performance.

In sum, the research thus far has not provided a clear picture of the relation between attentional control training and reading comprehension. The mixed results may relate to the complex role that dopamine (DA) plays in attentional control (Cools & D'Esposito, 2011). For example, one of the methods used to train attentional control in the studies just described was meditation, an intervention in which people consciously try to control their attention. A side effect of meditation is a large increase in DA levels in the brain (Kjaer et al., 2002). In the present study we aim to investigate the role of DA in attentional control to gain more insight in individual differences in attentional control during reading and how this is related to reading comprehension.

The Role of DA in Attentional Control

DA plays a key role in sustaining attention over prolonged periods of time during completion of tasks, such as reading long stretches of text, that require working memory to integrate information and update knowledge in memory (Boulougouris & Tsaltas, 2008; Westbrook & Braver, 2016). Studies with patients who suffer from reduced DA transmission in the brain due to for instance Parkinson's disease, ADHD, or brain lesions have shown that the ability to focus attention decreases, and distractibility increases, when the transmission of DA in the brain is impaired (Nieoullon, 2002). The prefrontal cortex, which is a DA rich area in the brain, is particularly involved in attentional control, and is highly sensitive to fluctuations in DA (see also Cools & D'Esposito, 2011; Shaywitz & Shaywitz, 2008).

DA levels in the brain can be pharmacologically manipulated by administering drugs containing levodopa. Levodopa is a precursor of DA, acting on DA receptors in, amongst other brain areas, the prefrontal cortex. Levodopa can restore decreased uptake of DA in the brain, resulting in higher DA levels and enhanced cognitive performance. This effect has been found in both clinical samples and healthy adults (see Moustafa et al., 2013). In line herewith, we wondered whether higher DA levels in the brain during reading might be beneficial for attentional control during reading. Although the number of DA administration studies involving cognitive outcomes has increased over the last ten to fifteen years, the exact influence of DA levels in different brain areas that are related to attentional processes (e.g., prefrontal cortex, anterior cingulate cortex, basal ganglia or caudate nucleus; see Shaywitz & Shaywitz, 2008) on performance on different kinds of cognitive tasks has not yet become clear (see Diamond et al., 2004; Nieoullon, 2002; Westbrook & Braver, 2016). Performance on some neuropsychological tasks that require attention (e.g., the dots-mix task) appeared to be sensitive to fluctuations in DA levels (particularly fluctuations in the prefrontal cortex; see Diamond et al., 2004), while performance on other tasks (e.g., a card sorting task tapping into cognitive flexibility) was not (Ko et al., 2009;).

The Role of DA in Memory Formation

DA is not only involved in attentional processes, but also in related processes such as memory formation (see e.g., Boulougouris & Tsaltas, 2008; Nieoullon, 2002). Similar to the results of the studies on DA and attention, the results of studies on DA and memory formation are mixed (see e.g., Cools & Robbins, 2004). For example, both Breitenstein, Flöel et al. (2006) and Knecht et al. (2004) found positive results associated with increased levels of DA on memory. Breitenstein, Flöel et al. (2006) found that healthy adults who were administered either levodopa or D-amphetamine (both aimed to increase DA levels in the brain) performed better on a word-learning task than adults in a placebo control group. Participants learned faster, learned more, and had better retention after one month when administered either levodopa or D-amphetamine. Similarly, Knecht et al. (2004) found that healthy adults who were administered levodopa learned faster, learned more, and had better retention than those in a placebo control group.

Other studies, however, have found no or negative effects of increased levels of DA. For example, Linssen et al. (2014) found that pharmacologically increasing DA levels in healthy adults with the same dose that was used in the studies by Knecht et al. (2004) and Breitenstein, Flöel et al. (2006) had negative effects on memory performance on a word learning task. Participants had to remember as many words as possible from a list of 30 words that was shown to them three times. Based on EEG data recorded during the word learning task Linssen et al. (2014) argued that administering levodopa slowed down memory processes during the task as was shown by delayed latencies of ERP components (P3b and P600) during the encoding phase of the word learning task. Nevertheless, behavioural data showed that performance on the word learning tasks, as well as two working memory tasks and an associate learning task were not influenced in a positive or negative way by the drug administration.

In sum, although there are some indications that on a neurobiological level increased DA levels in the brain have a negative effect on memory formation, on a behavioural level, negative effects are absent and in some studies even positive effects on memory performance were found.

Explaining the Diverging Effects of Increased DA on Cognitive Performance

Linssen et al. (2014) used the inverted U-shape theory as a possible explanation for not finding effects of pharmacologically increasing DA levels in the brain on (working) memory performance of healthy adults. According to this theory, the relation between DA levels in the brain and attention and memory formation follows an inverted U-shape (Vijayraghavan et al., 2007), that is, that both 'too-high' and 'too-low' levels can hinder cognitive performance. However, this theory does not explain the positive effects of pharmacologically increasing DA on memory performance that have been found in other studies with healthy adults (e.g., Breitenstein, Flöel et al., 2006; Knecht et al., 2004), who are expected to have optimal or close to optimal DA levels. As a consequence, a direct test for the inverted U-shape theory is needed. Therefore, in the present study we test the effects of increased levels of DA in a subgroup of people who are expected to have a well-functioning dopaminergic system, i.e., optimal DA levels in the brain, and in a subgroup of people with reduced DA levels in the brain.

One gene that is found to be related to both levels of DA in the brain and attentional control, is the dopamine D4 receptor (DRD4) gene (Bonvicini et al., 2020). People who are carrier of the DRD4 7-repeat allele (DRD4-7R), sometimes referred to as 'the long variant', show a less efficient DA transmission, resulting in lower levels of DA in the brain (Ariza et al., 2012) than people carrying other variants of the allele. Carrying the DRD4-7R allele also has been shown to be a risk factor for ADHD, a disorder marked by difficulties in attentional control (see e.g., Bonvicini et al., 2020). In line with this reasoning, people carrying the DRD4-7R may benefit more from increased levels of DA in the brain than people who carry other polymorphisms of the DRD4 gene.

Present Study

The aim of the present study is to investigate the effects of increased levels of DA on attentional control during reading and reading comprehension. To achieve this aim, we pharmacologically manipulated the DA levels in the brain of healthy female university students using a similar dosage of levodopa as was used in previous studies (e.g., Breitenstein, Flöel et al., 2006; Knecht et al., 2004; Linssen et al., 2014). To the best of our knowledge, the present study is the first one testing the effects of pharmacologically manipulating DA in the case of reading comprehension. Additionally, our research expands the current literature by directly testing the inverted U-shape theory. Because the effects of increased DA may differ as a consequence of differences in baseline levels of DA in the brain, we investigated the effect of increased DA in two subgroups that are expected to differ in baseline levels of DA in the brain: students who were carrier of the DRD4-7R allele and students who were not.

The present study employs a placebo-controlled double blind within-subjects experiment, in which healthy female students completed a reading task in one of two conditions (levodopa or placebo), after which their reading comprehension was measured. Based on previous research on DA and attentional control (see e.g., Boulougouris & Tsaltas, 2008; Nieoullon, 2002; Westbrook & Braver, 2016), we expect that administering levodopa will influence attentional control during reading. Additionally, in line with previous studies on the effects of administering levodopa on memory formation and word learning tasks (see Breitenstein, Flöel et al., 2006; Knecht et al., 2004; Linssen et al., 2014), we also expected administering levodopa to influence reading comprehension. In line with the inverted U-shape theory (Boulougouris & Tsaltas, 2008; Cools & D'Esposito, 2011; Vijayraghavan et al., 2007) and the fact that the DRD4-7R allele is related to reduced levels of DA (Ariza et al., 2012), we expected, on the one hand, that positive effects of levodopa would be particularly prominent in students carrying the DRD4-7R allele (i.e., less optimal DA levels), and on the other hand that increases in DA levels would result in a decrease in attentional control during reading and reading performance in the subgroup of students not carrying the DRD4-7R allele.

The present study takes a multimethod approach to measure attentional control during reading by measuring attentional control on both a biophysiological level and behavioural level. Recent research has shown that EEG data, specifically the frontal theta/beta ratio (TBR) might provide a biophysiological maker of attentional control during reading (Swart et al., 2020). In line with previous research on the relation between attentional control, fluctuations in attentional control, and (fluctuations in) frontal TBR in other cognitive tasks (e.g., van Son et al., 2019a), the study of Swart et al (2020) showed that both the average frontal TBR and fluctuations in frontal TBR are related to attentional control and fluctuations in attentional control. We take a similar multi-method approach to gain a thorough understanding of the effect of increased DA on reading comprehension, in the present study we investigate comprehension on both text-level and word-level. For text-level comprehension we combined two tasks, a summary writing task and reading comprehension questions. For word-level comprehension, we take both the breadth (i.e., the number of words participants learn after reading) and depth (i.e., knowledge on both word form and semantics; see e.g., Nation, 2020) of word-level comprehension into account by combining four tasks that each tap different levels of knowledge about the words in the text, ranging from questions on word form level to questions on passive and active semantic knowledge of a word.

Methods

Research Design

The experiment had a randomized, double-blind placebo-controlled within-subjects design. A total of 80 participants were submitted to two experimental conditions (levodopa and placebo) at two separate lab sessions. In the levodopa condition, participants were administered Sinemet125 (containing 100mg levodopa and 25mg carbidopa) at the beginning of the lab session, in the placebo condition participants took a placebo capsule. All medication was produced in identical capsules. To ensure that the study design was double-blind, randomization of the order of treatments (levodopa or placebo) and the order of texts that were read in both experimental sessions (text A and text B) was carried out by the university hospital pharmacy, resulting in four different combinations of the order of treatment condition and text. Before starting the research, its design and methodology were approved by the Education and Child Studies ethics committee of Leiden University (project ID: ECPW-2014/077) and the medical ethics committee of the Leiden University Medical Centre (project ID: NL49379.058.14).

Participants

An initial sample of 200 Dutch female undergraduate students were recruited via advertisements placed in university buildings and student houses and on social media. The total number of recruited students was based on the world-wide average prevalence of the DRD4 7-repeat genotype (20.7%; e.g., Chang et al., 1996). In order to end up with 40 participants with the DRD4 7-repeat allele, approximately five times as much participants had to be recruited. Because of gender differences in DA levels in the brain between men and women (see e.g., Munro et al., 2006) and the large proportion of female students within the faculty, it was decided to include only female participants. Participants had to be 18 years or older and right-handed. Students with dyslexia, medical illnesses indicating a risk in using haloperidol (e.g., cardiac illness, depression, thyroid disorders, or glaucoma), or known drug allergies, and students who were pregnant or lactating were excluded from participation in the study. Students also were excluded if they were using medication (other than contraceptives) or drugs in the two weeks prior to the experiment. After genotyping, 80 students (M_{age} 21.38 years, SD = 1,84; 40 participants carrying the DRD4-7r allele, and 40 participants who did not) were selected to participate in the experimental sessions.

Procedures

Buccal swabs were collected from all participants. DNA was isolated and variable number of tandem repeats (VNTR) genotyping was performed for the DRD4-gene by an external genomics company. Based on these results, participants were grouped in two subgroups: one group of participants carrying at least one DRD4 7-repeat allele (DRD4 7+) and one group carrying two shorter alleles (DRD4 7-). Each student that was selected after genotyping participated in two lab sessions on two separate days. Students were not informed about the individual results of the genotyping, so they were unaware of the genotype they carried.

At the beginning of the lab sessions, participants received capsules containing either Sinemet125 (release time of the ingredients is approximately 30 minutes; IBM Micromedex) or the placebo and took the capsules orally. The experiment was double-blind, which means that neither the participant, nor the experimenter knew whether Sinemet125 or the placebo was given to the participant. Except for one participant reporting nausea in the placebo condition, no side effects of the medication were reported by the participants. Immediately after administering the capsules during the first session, measures of executive functioning, attentional control, reading motivation and language skills were administered to control for comparability on these factors across the DRD4+ and DRD4- groups (for details on the measurement instruments for these background variables, see Appendix A).

Forty-five to sixty minutes after administration, the participant read a narrative text of approximately 4000 words. Participants read one of two passages from a Dutch translation of the novel *A Clockwork Orange* (Burgess, translated by Damsma & Miedema, 2012) that were selected for the present study. The passages were taken from two separate chapters of the book and were understandable without knowing the rest of the storyline. Events in the two chapters did not necessarily have to take place in the order in which the events actually appeared in the book, making counterbalancing of the order of the two texts possible. Text A consisted of 4049 words divided among 16 pages, and text B consisted of 4098 words divided among 17 pages. The texts respectively included 201 (text A, 5.0% of the total number of words) and 188 (text B, 4.6% of the total number of words) nonsense words from the fictional Nadsat language that was spoken by some of the characters in the novel.

Attentional control during reading was measured using the average frontal theta/beta-ratio (TBR) during reading and the *SD* in frontal TBR among the text pages (see Swart et al., 2020) and by a retrospective self-report that was administered directly after reading. Frontal TBR was extracted from the EEG-recording during reading. Immediately after reading the text, participants were provided with a paper version of the text and were asked to mark moments in the text where they remembered being distracted from the text.

After self-reporting their attentional control during reading, participants were asked to write a summary of max. 5000 characters about the story they had just read and to answer open comprehension questions about the text (28 for text A and 24 for text B). Subsequently, participants completed four tasks concerning word-level comprehension.

Measurement Instruments

Frontal TBR During Reading

EEG data were recorded during a baseline period (three minutes eyes-closed and three minutes eyes-open) and during reading. We used 129-channel hydrocel Geodesic sensor nets and electrodes, which were placed according to the 10-20 system amplified by a NetAmps300 amplifier at a digitization rate of 500Hz (Electrical Geodesics Inc.). Impedances were kept below 50 kΩ. Raw data were further processed offline using Brain Vision Analyzer 2.0 software (Brain Products). Data were low-pass filtered at 100 Hz (-3 dB, 48 dB/oct) and high-pass filtered at 0.3 Hz (99.9% pass-band gain, 0.1% stop-band gain, 1.5 Hz roll-off) with a notch-filter of 50 Hz to eliminate electrical noise. Subsequently, EEG data were referenced to the average activity in all channels and ocular correction was performed using Gratton & Coles' procedure (Gratton et al., 1983). To retain as much artefact-free data as possible, raw EEG data were segmented in 2 second segments with an overlap of 5%. Segments containing artefacts (defined as: voltage steps exceeding 50 µV/ms, differences in values above 100 µV within an interval of 200 ms, amplitudes lower than -70 µV or higher than 70 µV or segments containing less than 0.5 µV activity in intervals of 100 ms intervals) were excluded from further analyses. In addition, noisy channels were replaced by average activity of the closest electrodes. After segmenting the data and correcting for artefacts, power densities in the theta (4-7 Hz) and beta (13-30 Hz) frequency bands were calculated by performing a fast Fourier transformation (resolution 0.25 Hz, hamming window 10%).

Frontal TBR was calculated for each text page, based on the average power density of three frontal electrodes (F3, Fz, and F4, represented by electrode numbers 24, 11, and 124 respectively; Putman et al., 2014; Swart et al., 2020). Because of non-normality, power density values within each frequency band were log-normalized before calculating the ratios. The average frontal TBR during reading was calculated by averaging frontal TBR for all text pages within each text. Higher ratios reflected lower attentional control during reading and lower scores reflected better attentional control during reading (see e.g., Putman et al., 2014; van Son et al., 2019a). The *SD* among the average frontal

TBRs for each text page within each text was calculated as an indicator for fluctuations in frontal TBR during reading.

Self-Reports of Attentional Control During Reading

For each moment in the text that a participant marked as being distracted, the experimenter asked the participant what she was thinking at that moment. All self-reports were scored by an undergraduate student and the first author to distinguish comments that reflected constructing meaning from the text during reading (e.g., "When I read this sentence, I thought back to a scene at the beginning of the text") vs. comments that reflected being distracted during reading (e.g., "At this part of the text I was not paying attention to the text anymore, but I was thinking about what I would buy for dinner after finishing the experiment"). The total number of marked moments in the text that reflected moments of distraction was used as an indication for attentional control during reading. Disagreements in scoring were resolved through discussion until consensus was reached. Inter-coder reliability was ICC = .96 ($p < .001$) for self-reports of attentional control during text A and ICC = 1.00 ($p < .001$) for self-reports on attentional control during text B.

Summary Task

Participants' summaries were scored for the number of main elements in the text that were included in the summary. Main elements in the texts were selected based on the Event-Indexing Model (Zwaan et al., 1995) and, in line with the model, included information on time, space, protagonists, causality, and intentionality of story events. The percentage of the correctly mentioned elements for each text was calculated. All summaries were scored by two trained undergraduate students. Inter-coder reliability was ICC = 1.00 ($p <.001$) for the summaries of text A and ICC = 1.00 ($p <.001$) for the summaries of text B. Disagreements in scoring were resolved through discussion until consensus was reached.

Text-Level Comprehension Questions

Correct answers to the open comprehension questions about the content of the text (27 for text A and 24 for text B) were awarded one point. If an answer contained two components (e.g., two reasons why the main character in the story did not want to go to school), participants could receive half a point for mentioning one of the two components. A proportion of the correct answers from the maximum scores was calculated for each text. All answers were scored by two trained undergraduate students. Inter-coder reliability was ICC = .98 (p <.001) for the questions of text A and ICC = .96 (p <.001) for the questions of text B. Disagreements in scoring were resolved through discussion until consensus was reached.

Word-Level Comprehension Questions

Participants completed four tasks concerning 30 of the nonsense words from the fictional Nadsat language that was spoken by some of the characters in the novel. All four tasks concerned the same 30 nonsense words per text. First, participants were asked to fill in a nonsense word that they remembered from the text that would fit in one of the 30 new sentences that did not appear in the text (sentence task). Second, participants were shown a list of the 30 nonsense words and were asked to fill in one or two missing letters in each word (spelling questions). Third, participants were shown the 30 nonsense words and were asked to fill in the meaning of the 30 nonsense words (open word meaning questions). Fourth, for each word the participants had to choose the correct Dutch meaning of the nonsense words out of three alternatives (MC word meaning questions). A total score (max. 30 points) was calculated for each task based on the number of correct answers. All answers were scored by two trained undergraduate students. Inter-coder reliability for all word-level comprehension tasks was on average ICC = .98 (range: .93 – 1.00, all p's < .001). Disagreements in scoring were resolved through discussion until consensus was reached.

Results

Descriptive Results

The final sample consisted of 40 students with the DRD4 7+ genotype and 40 students with the DRD4 7- genotype. Students in the two groups did not differ in age, reading motivation, language skills, executive functioning or attentional control in daily life (see Table 1). Reading times did not differ between the levodopa condition (M = 18.02 minutes, SD = 4.34) and the placebo condition (M = 18.64 minutes, SD = 5.02, t(78) = 1.60, p = .11). Data on all outcome variables were complete for all participants, except for frontal TBR during reading, and the self-reports on attentional control. Missing data were due to technical issues. Frontal TBR data in the levodopa condition were missing for one participant in the DRD4 7+ group. Scores on the self-report on attentional control during reading were missing for two participants in the DRD4 7- group, one in the levodopa condition and one in the placebo condition. One participant had an outlying score (z > 3.29;

Tabachnik & Fidell, 2007) for frontal TBR in the levodopa condition, *SD* in frontal TBR in both conditions and on the self-report in both conditions. We excluded this participant from further analyses regarding attentional control. The scores on the sentence completion (word-level comprehension) subtest were highly skewed (standardized skewness placebo condition = 4.67, levodopa condition = 15.87). This subtest appeared to be too difficult for the participants. In the placebo condition 65.0% of the participants scored zero points on the test and in the levodopa condition, 72.5% of the participants scored zero points. The scores on this subtest were, therefore, not included in further analyses. Data for all outcome measures in both conditions, broken down by genotype subgroup, are shown in Table 2.

We performed the following repeated measures ANOVAs to test the effects of increasing DA levels (levodopa vs. placebo as a within subject factor) on attentional control and reading comprehension both with and without DRD4 genotype as a between-subjects factor. No main effects of DRD4 genotype or interaction effects involving DRD4 genotype were found (for the results, see Appendix B). We, therefore, report the results for the model that includes only the within-subjects factors condition (levodopa vs. placebo) and type of outcome measure (for attentional control: average frontal TBR, *SD* in frontal TBR and self-report; for reading comprehension: summary task, text-level comprehension questions, spelling questions, MC word meaning questions, and open word meaning questions).

The Effects of Dopamine on Attentional Control During Reading

In order to include the scores on the three attentional control measures (average frontal TBR during reading, *SD* in frontal TBR during reading, and self-reports) in one analysis, we decided in consultation with a stastical expert to calculate the proportion of each score of the maximum observed score for that attentional control measure to end up with similar scales for each measure. A repeated measures ANOVA with condition (levodopa vs. placebo) and type of attentional control measure (frontal TBR during reading, *SD* in frontal TBR during reading and self-reports of attentional control during reading) as within subject factors showed no main effect of condition (F (1,75) = 1.48, p = .23, η_p^2 = .02). Attentional control during reading did not differ between the levodopa condition and the placebo condition. The main effect of type of attentional control measure was significant (F(1,75) = 40.73, p < .001, η_p^2 = .35), showing that the proportional scores for the average frontal TBR during reading (M = .41, SD = .16), *SD* in frontal TBR during reading (M = .25, SD = .10), and scores for the self-reports (M = .22, SD = .15) varied. No interaction effect was found for condition and type of attentional control measure on attentional control during reading (F (1,75) = 1.27, p = .29, η_p^2 = .02).

The Effects of Dopamine on Reading Comprehension

A repeated measures MANOVA was performed with condition (levodopa vs. placebo) and type of reading comprehension measure (summary task, text-level comprehension questions, spelling questions, open word meaning questions, and MC word meaning questions) as within subject factors. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of type of outcome measure (χ^2 (9) = 116.95, $p < .001$) and the interaction effect of condition and type of outcome measure (χ^2 (9) = 110.45, $p < .001$). Therefore, degrees of freedom for these effects were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .62$ for the main effect of condition and $\varepsilon = .57$ for the interaction effect of condition and type of outcome measure). There was a significant main effect of condition on reading comprehension ($F(1,79) = 11.55$, $p = .001$, $\eta_p^2 = .13$). Participants performed worse on reading comprehension in the levodopa condition than in the placebo condition. This effect was moderate. The main effect of type of reading comprehension measure was significant ($F(2.50,197.19) = 334.77$, $p < .001$, $\eta_p^2 = .81$), showing that the mean scores of participants varied among the comprehension tasks. In other words, participants perceived some tasks as more difficult than others, particularly the spelling task and the open word meaning questions (for means and *SD*s, see Table 3). No significant interaction effect of condition and type of outcome measure on reading comprehension was found ($F(2.27,179.51) = .93$, $p = .41$, $\eta_p^2 = .01$). Lepodova had a similar effect on the different comprehension measures.

Discussion

The aim of the present study was to gain insight into the neurobiological processes, particularly dopaminergic mechanisms, underlying attentional control during reading and reading comprehension by investigating the effects of pharmacologically increasing DA. To the best of our knowledge, the present study is the first study to investigate the effects of pharmacologically manipulating DA in the field of reading comprehension. In order to test the effects of increased DA in the brain, university students participated in a placebo-controlled within-subject experiment in which they were orally administered either levodopa, a precursor of DA in the brain, or a placebo before reading a text. In order to directly test the inverted U-shape theory concerning the effects of DA on cognitive performance (see Boulougouris & Tsaltas, 2008; Cools & D'Esposito, 2011; Vijayraghavan et al., 2007), two subgroups of students were included in the experiment: one group of students carrying the DRD4 7R allele and one group of students who did not. No differences in attentional control between the DRD4 7+ and the DRD4 7- groups were found at the start of the study. Also, a first set of analyses showed no main effects of DRD4 genotype or interaction effects of DRD4 genotype and condition or type of outcome measure, neither for attentional control during reading nor for reading comprehension. As a consequence, DRD4 genotype was not included as a between-subjects factor in the core analyses of the present study. Results of the core analyses showed that increased levels of DA did not affect attentional control during reading in a positive or negative way, as measured on both a neurobiological and behavioural level. However, on a behavioural level, increased levels of DA influenced reading comprehension in a negative way. That is, students performed significantly worse on the comprehension tasks when reading a text in the levodopa condition than in the placebo condition. This effect was moderate.

DRD4 Genotype and the Inverted U-Shape Theory

In line with the inverted U-shape theory (see Boulougouris & Tsaltas, 2008; Cools & D'Esposito, 2011; Vijayraghavan et al., 2007), we expected that pharmacologically increasing DA would particularly enhance attentional control during reading and reading performance in adults carrying the DRD4-7R allele, which has shown to be related to a less efficient transmission of DA in the brain, resulting in lower levels of DA in the brain (Ariza et al., 2012). As a consequence, we expected that the levels of DA in the brain of this group of adults would be situated left from the top of the inverted U-shape and that, therefore, they would be more susceptible for the positive effects of administering levodopa. Contrary to what was expected, there were no differences in attentional control between the two groups at pretest and no interaction effects of DRD4 genotype and condition were found, suggesting that the students from the DRD4 7+ and DRD4 7- groups did not differ in DA levels at pretest.

It is possible that the reduced levels of DA in the brain that are related to the DRD4 7+ genotype are particularly problematic in younger children. Bonvicini et al. (2020) found the DRD4-7R allele to be a major risk factor for ADHD, but only for children. The association was not present for adults. Other studies also have shown that the relation between DRD4 genotype and ADHD symptoms decreases with age (Bonvicini et al., 2018). If all participants, both those who carry the DRD4 7R allele and those who do not, are on average already located near or at the top of the inverted U-shape model regarding the levels of DA in the brain, it would mean that pharmacologically increasing DA would have no effect or possibly even a negative effect on attentional control and reading comprehension.

The Effects of Dopamine and Attentional Control During Reading

Despite the key role of DA in attentional control processes that has been found in previous studies (see e.g., Boulougouris & Tsaltas, 2008; Nieoullon, 2002; Westbrook & Braver, 2016), increased levels of DA did not increase or decrease attentional control during reading as measured by the average frontal TBR during reading, fluctuations in frontal TBR during reading, and a retrospective self-report. A possible explanation for not finding an effect of increased DA on attentional control during reading might be the limited sensitivity of the average frontal TBR to fluctuations in attentional control while reading the text. Ups and downs in attentional control average out in the overall average frontal TBR for the whole text. As a consequence, no conclusions could be formed on the effect of DA on the amount of fluctuations in attentional control based on this attentional control outcome measure. Nevertheless, the average frontal TBR during reading might still be informative as a broad measure of attentional control during reading. Results from a previous study showed that the average frontal TBR was moderately to strongly related to attentional control in daily life and to text-level reading comprehension (Swart et al., 2020). However, although the texts used in both the current and the previous study came from the same chapters of the novel ‘A Clockwork Orange’, the texts in the present study were 1500 words longer than those used in the previous study, and participants took nearly twice as long to read the longer texts. Longer tasks might evoke more lapses of attention which may not be reflected in an average score of attentional control during reading (see Krimsky et al., 2017).

Whereas the average frontal TBR provides a broad measure of the average attentional control during reading, the self-report measure of attentional control included in the present study could be informative on the point of fluctuations in attentional control. However, we also did not find an effect of DA on attentional control for these outcome measures. Possibly, meta-awareness could have confounded the results for this measure. Self-awareness is required for reporting moments of distraction during reading. However, research has shown that readers are not always aware that they fail to control attention. Additionally, it is the lapses in attentional control that readers are not aware of that are most detrimental for memory formation (for a review see Smallwood & Schooler, 2015). Such lapses are obviously not reflected in a self-report measure. Nevertheless, the absence of an effect of increasing DA on self-reports of attentional control is in line with the results for fluctuations in frontal TBR found in the present study.

The Effects of Dopamine on Reading Comprehension

In line with previous studies on the effects of administering levodopa on memory formation and word learning tasks (see Breitenstein, Flöel et al., 2006; Knecht et al., 2004; Linssen et al., 2014), we expected administering levodopa to influence reading comprehension. In the present study we found that administering levodopa negatively influenced reading comprehension, i.e., the formation of a mental representation of a text. According to Linssen et al. (2014), on a neurological level, the encoding of information in long-term memory, which is crucial for the formation of a mental representation of a text, is slowed down as a consequence of administering levodopa. However, although Linssen et al. (2014) found negative effects of administering levodopa on memory formation on a neurological level but not on a behavioural level, in the present study we found negative effects on memory formation (i.e., the mental representation of the text) on a behavioural level (i.e., performance on the reading comprehension outcome measures) and no effect on a neurological level.

If the negative effects of administering levodopa on reading comprehension would, in line with Linssen et al.'s (2014) reasoning, be the consequence of slower memory processing (i.e., on a neurological level), it would have taken readers more time to construct a mental representation of the text and they would have had to allocate more attentional resources to process the information in the text. This would then have resulted in longer reading times in the levodopa condition compared to the placebo condition. However, no differences in attentional control and reading times between the levodopa condition and the placebo condition were found in the present study.

A possible dopamine-related mechanism that could account for the negative effect of administering levodopa on reading comprehension is that participants in the present study experienced a flattened emotional responsiveness to information in the text during reading as a consequence of the pharmacological manipulation of DA. Pharmacological manipulation of DA levels using levodopa is aimed at increasing both tonic levels of DA (i.e., sustained background levels) and phasic levels (i.e., short-term activations) of DA in the brain (Breitenstein, Korsukewitz et al., 2006). However, Breitenstein, Korsukewitz et al. (2006) argued, based on an experiment with healthy adults in which they pharmacologically manipulated only tonic DA levels in the brain, that the dynamic combination of levels of phasic and tonic DA in the brain is a delicate balance (see also Linssen et al., 2014). Tonic increases in DA that are too large may lead to a reduction of phasic DA activity in healthy adults. As a consequence of pharmacologically increasing tonic DA, healthy adults in the experimental study of Breitenstein, Korsukewitz et al. (2006) showed flattened emotional responsivity and impaired learning, which was, according to Breitenstein, Korsukewitz et al. (2006) related to a decrease in phasic DA activity. If participants in the present study experienced a comparable flattened emotional responsiveness to information in the text during reading, this could have led to less task engagement during reading. In line with the engagement perspective of reading (see Klauda & Guthrie, 2015), lowered engagement during reading could have led to a more superficial processing of the information in the text, resulting in a less coherent and complete mental representation of the text, hindering learning from text (van den Broek et al., 2005). Additionally, phasic DA appears to be particularly important for updating working memory knowledge (see Westbrook & Braver, 2016), which is a crucial process for reading comprehension (Palladino et al., 2001). If an excessive increase in tonic DA leads to reduced phasic DA activity, readers could have experienced difficulties in updating working memory in the levodopa condition, and, as a consequence, they could have had difficulties updating the mental representation of the text.

Another possible explanation for the negative effect of pharmacologically increasing DA on reading comprehension might be the difference in the reading task used in the present study compared to the word learning tasks used in previous research in which the effects of pharmacologically increasing DA on learning were tested (see Knecht et al., 2004, Breitenstein, Flöel et al, 2006; Linssen et al., 2014). In these studies, participants listened to single words being read to them. These tasks included much repetition, which could have caused boredom in participants, as was also argued by Knecht et al. (2004). In that case, pharmacologically increasing DA might have helped participants to perceive the task as more positive, i.e., less boring, because increased DA helps participants to interpret neutral stimuli as more positive or salient (Tripp & Wickens, 2008). In the case of reading comprehension, manipulating the experienced salience of information through pharmacologically increasing DA levels in the brain, which results in perceiving less salient information as salient and/or important, could have consequences for distinguishing main issues and side issues from the text. Participants' sensitivity to structural centrality of information in the text could have been hindered, which negatively influences reading comprehension (Kendeou et al., 2014).

Suggestions for Future Research

To further disentangle the dopamine-related mechanisms that might explain the effects of increased DA on attentional control and reading comprehension, future research should investigate the effects of increased DA on other cognitive processes that are related to attentional control and memory formation, such as working memory and goal-directed behaviour, that closely overlap with the neural correlates of attention (see e.g., Wass et al., 2012) and also rely on dopaminergic systems (see e.g., Cools & D'Esposito, 2011). A complementary approach in which these processes are measured in both the levodopa and the placebo condition could provide further insight in the mechanisms underlying attentional control and reading comprehension. Additionally, the combination of physiological and behavioural measures could help to gain insight in both neurobiological and behavioural effects of DA. In the present study, the outcomes on both physiological and self-report measures of attentional control during reading point in the same direction, i.e., neither a positive nor a negative effect of increased DA on attentional control. However, in previous studies, effects of increased levels of DA on physiological measures and behavioural measures of cognitive processing varied (e.g., ERP latencies vs. learning accuracy and learning speed, see Linssen et al., 2014). Finally, the effects of the number of levodopa dosages should be investigated on both a psychophysiological and behavioural level, because the effects of pharmacologically increasing DA differs across time spans of the experimental learning tasks used in previous studies and the present one. In the study of Linssen et al. (2014), only a negative psychophysiological effect of administering levodopa was found, but no behavioural effects. In the present study, in which we also administered a single dose of levodopa, the results were contradictory. No psychophysiological effects were found, i.e., no difference in the average frontal TBR during reading, but negative effects were found on a behavioural level, i.e., impaired reading comprehension. In the studies that used a similar daily dose, but a longer five-day word-learning intervention (Breitenstein, Flöel et al., 2006; Knecht et al., 2004), positive effects were found on a behavioural level.

Conclusions

In conclusion, the results of the present study, which is to the best of our knowledge the first one testing the effects of pharmacologically increasing DA on reading comprehension including participants who might be expected to differ in DA uptake in the brain as a consequence of their genotype, showed that increased levels of DA did not influence attentional control during reading as measured by the average frontal TBR during reading, fluctuations in frontal TBR during reading, and a retrospective self-report, but negatively influenced reading comprehension in healthy female university students. In other words, although the ability to attentively read and understand longer stretches of texts is crucial for success in academic, professional and personal life, pharmacologically optimizing reading comprehension and attentional control, is a complex issue that requires a more thorough understanding of the neurobiological processes and mechanisms underlying these complex skills. Because of diverging findings in the present study and previous studies regarding the effects of pharmacologically increasing DA on both a neurobiological and behavioural level of cognitive processes and the difference in duration and complexity of learning tasks, more research and replication studies are needed to further unravel the dopamine-related mechanisms that could explain these effects.

Table 1

Descriptive Statistics for the Demographic Variables for Participants with the DRD4 7- Genotype (n = 40) and the DRD4 7+ Genotype (n = 40)

Variable	Genotype	Min.	Max.	*M*	*SD*	*t*(78)	*p*
Age (in years)	DRD4 7-	18	27	21.58	2.01	0.82	.41
	DRD4 7+	18	24	21.18	1.65		
Reading Motivation	DRD4 7-	-3.63	1.66	-0.11	1.05	-0.83	.41
	DRD4 7+	-2.20	2.03	0.11	0.95		
Language skills	DRD4 7-	-1.60	1.63	-0.03	0.93	-0.19	.85
	DRD4 7+	-1.78	3.53	0.03	1.08		
Executive functioning (BRIEF-A)	DRD4 7-	78	167	114.13	20.81	0.52	.60
	DRD4 7+	75	178	111.62	21.86		
Attentional Control (ACS)	DRD4 7-	31	76	53.30	9.01	-0.39	.70
	DRD4 7+	40	69	53.80	8.00		

Table 2

Descriptive Statistics for Outcome Measures in the Levodopa Condition and the Placebo Condition, Separated per Subgroup of Genotype (N = 80).

Outcome measure	Subgroups	Levodopa condition			Placebo condition		
		n	*M*	*SD*	*n*	*M*	*SD*
Average frontal TBR during reading	DRD4 7-	40	.40	.24	40	.40	.18
	DRD4 7+	39	.39	.16	40	.38	.17
	Total	79	.40	.20	80	.39	.17
SD in frontal TBR during reading	DRD4 7-	39	.09	.07	39	.08	.05
	DRD4 +	39	.10	.05	40	.09	.06
	Total	78	.09	.06	79	.09	.05
Self-reported attention during reading	DRD4 7-	39	3.23	3.07	39	3.33	2.85
	DRD4 7+	40	2.73	2.45	40	2.85	2.03
	Total	79	3.09	2.47	79	2.97	2.76
Summary task (% correct mentioned main events)	DRD4 7-	40	24.21	13.44	40	24.29	13.54
	DRD4 7+	40	25.18	13.93	40	26.66	12.79
	Total	80	24.70	13.61	80	25.47	13.14
Text-level comprehension questions (% correct)	DRD4 7-	40	33.73	19.47	40	37.66	19.32
	DRD4 7+	40	29.90	15.59	40	35.78	15.91
	Total	80	31.82	17.63	80	36.72	17.61

Outcome measure	Subgroups	Levodopa condition			Placebo condition		
		n	*M*	*SD*	*n*	*M*	*SD*
Spelling questions (% correct)	DRD4 7-	40	7.75	5.62	40	10.67	6.97
	DRD4 7+	40	8.92	5.91	40	10.33	8.80
	Total	80	8.33	5.76	80	10.50	7.89
MC word meaning questions (% correct)	DRD4 7-	40	45.08	9.31	40	45.67	12.43
	DRD4 7+	40	42.92	9.52	40	48.08	14.65
	Total	80	44.00	9.42	80	46.88	13.56
Open word meaning questions (% correct)	DRD4 7-	40	4.58	5.37	40	6.25	6.32
	DRD4 7+	40	5.00	5.99	40	6.58	8.08
	Total	80	4.79	5.66	80	6.42	7.21

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Table 3

Estimated Marginal Means of the Main Effect of Type of Reading Comprehension Measure (N = 80).

Reading comprehension measure	*M*	*SE*
Summary task	25.08	1.23
Text-level comprehension questions	34.27	1.59
Spelling questions	9.42	0.62
MC word meaning questions	5.60	0.52
Open word meaning questions	45.43	1.00

Appendix A

Background Variables

Executive Functioning

Participants completed the Behavior Rating Inventory of Executive Function—Adult version (BRIEF-A; Scholte & Noens, 2011), a self-report questionnaire of 75 items designed to examine adult's executive functions in daily life. Participants rated the frequency of the described behaviours on a 3-point scale (1 = never, 2 = sometimes, 3 = often). Scores on the BRIEF-A range from 75 to 225, with a lower score reflecting better executive functioning. A total score was calculated for each participant. Internal consistency of the scale in the present study was Cronbach's α = .96.

Attentional Control

Participants completed a Dutch translation of the Attentional Control Scale (ACS; Derryberry & Reed, 2002). Participants rated twenty statements about attention and concentration in daily life on a four-point Likert-scale (e.g., 'It's very hard for me to concentrate on a difficult task when there are noises around', 'It is easy for me to switch between two different tasks' and 'After being disrupted or distracted, it is easy for me to shift my attention away from the distractor'). Scores on the ACS range from 20 to 80 points, with a higher score reflecting better attentional control in daily life. A sum score for all items was calculated for each participant. Internal consistency was Cronbach's α = .85.

Reading Motivation

Participants completed a researcher-constructed reading motivation survey. The survey consisted of three subscales: engagement in reading related activities (13 items, e.g., 'If I like a book of a certain author I will read more books of the same author', 'I am a member of a book club', 'I regularly go to a book store to see if there are nice books'; Cronbach's α = .71), attitude towards reading for pleasure (21 items, e.g., 'Reading a book for pleasure is amusing', 'Reading a book for pleasure is boring'; Cronbach's α = .82), and reading in spare time (12 items, e.g., 'Reading a book costs me too much of my spare time', 'I only read if I have to', 'I always read before I go to sleep'; Cronbach's α = .81). Items were based on and extensions of the *Reading Attitude Scale* (Aarnoutse & Konings, 2013), the 'Reading Involvement' and 'Social Reasons for Reading' subscales of the *Motivations for Reading Questionnaire* (MRQ; Wigfield & Guthrie, 1997), the 'Value of Reading' subscale of the *Motivation to Read Profile* (MRP; Gambrell et al., 1996), and the *Self-Regulation*

Questionnaire-Reading Motivation (de Naeghel et al., 2012). Participants rated their agreement with statements on a 5-point Likert-scale, with higher scores indicating higher agreement. Negative statements were recoded so that higher scores on statements reflected a more positive attitude or more motivation. Principal components analysis applied to the three subscales resulted in one component, containing component loadings ranging from .77 to .88, explaining 70.1% of the variance. Higher aggregate scores reflected higher reading motivation.

Language Skills

Participants completed a researcher-constructed language test, containing four subtests: spelling, grammar, vocabulary and syntax. For the spelling subtest, participants had to complete the spelling for 40 words in which one or two letters were missing. In the grammar subtest (15 items), participants had to choose the right form of a verb, noun, or pronoun from two options. For both the spelling and the grammar subtest, one point was awarded for each correct answer. For the vocabulary subtest, participants had to determine whether words were real words or nonsense words from a list of 68 words containing 51 real words and 17 nonsense words. A total score was calculated by adding all correctly recognized real words minus the nonsense words that were incorrectly categorized as real word. Finally, participants had to complete twenty MC-questions about the form and meaning of several sentences. One point was awarded for each correct answer. Principal components analysis applied to the four subtests resulted in one component containing component loadings ranging from .68 to .76, explaining 51.5% of the variance. Higher aggregate scores reflected better language skills.

Appendix B

Table S1

Repeated Measures ANOVA Statistics for the Effect of DA on Attentional Control Including Main and Interaction Effects of the DRD4 Genotype (n = 76).

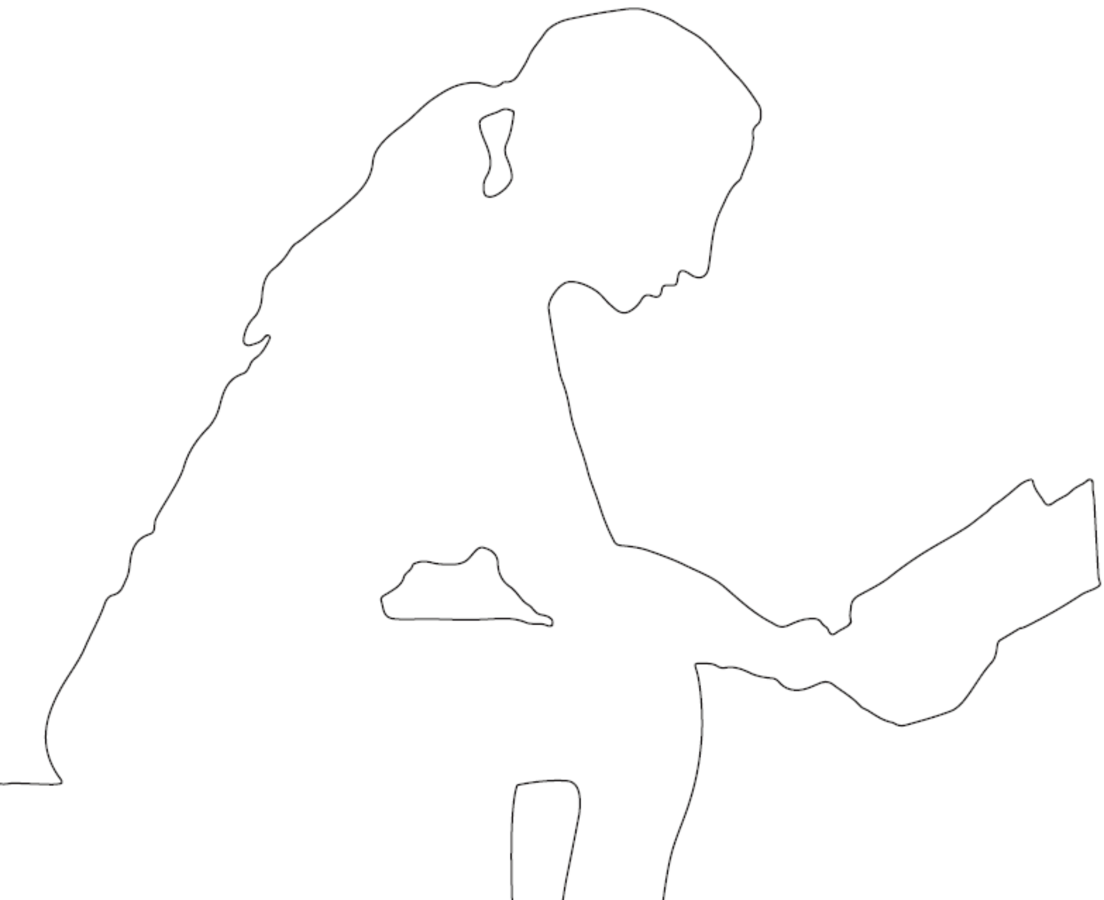
Effects	ANOVA statistics		
	$F(1,74)$	p	η_p^2
Main effects			
Condition	1.56	.22	.021
DRD4 genotype	.02	.88	.000
Type of attentional control measure	40.39	<.001	.353
Two-way interactions			
Condition * DRD4 genotype	1.14	.29	.015
Type of attentional control measure * DRD4 genotype	.44	.65	.006
Condition * Type of attentional control measure	1.26	.29	.017
Three-way interaction			
Condition * DRD4 genotype * Type of attentional control measure	.43	.65	.006

Table S2

Repeated Measures ANOVA Statistics for the Effect of DA on Reading Comprehension Including Main and Interaction Effects of the DRD4 Genotype (n = 80).

Effects	ANOVA statistics			
	F	*df*	*p*	η_p^2
Main effects				
Condition	11.52	1,78	.001	.129
DRD4 genotype	.001	1,78	.97	.000
Type of reading comprehension measure	334.09	2.49, 194.06	< .001	.811
Two-way interactions				
Condition * DRD4 genotype	.76	1,78	.39	.010
Type of reading comprehension measure * DRD4 genotype	.84	2.49, 194.06	.46	.011
Condition * Type of reading comprehension measure	.93	2.26, 176.02	.41	.012
Three-way interaction				
Condition * DRD4 genotype * Type of reading comprehension measure	.50	2.26, 176.02	.63	.006

Note. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of type of reading comprehension measure (χ^2 (9) = 115.11, p < .001) and the interaction effect of condition and type of reading comprehension measure (χ^2 (9) = 111.02, p < .001). Therefore, degrees of freedom for these effects were corrected using Greenhouse-Geisser estimates of sphericity (ε = .62 for the main effect of condition and ε = .56 for the interaction effect of condition and type of reading comprehension measure).



Chapter 4

Supporting Learning From Text: A Meta-Analysis on the Timing and Content of Effective Feedback

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Abstract

The aim of the present meta-analysis was to examine the effects of feedback on learning from text in conventional readers (ranging from primary school students to university students). Combining 104 contrasts of conditions of reading texts with and without feedback, including 6,124 participants, using the random effects model resulted in a positive effect of feedback on learning from text (g+ = 0.35). Moderator analyses showed that feedback is particularly effective if provided directly after reading, but less so when provided during reading. If feedback is provided directly after reading, elaborate feedback and knowledge-of-correct-response feedback were more effective than knowledge-of-response feedback. If feedback is provided during reading, no differences are found between the effects of different types of feedback. Additionally, computer-delivered feedback is more beneficial for learning from text than non-computer-delivered feedback. Implications for optimizing conditions to support learning from text are discussed.

Keywords: learning from text, reading comprehension, feedback, computer-assisted learning, cognitive load theory

Introduction

Although reading comprehension is an essential skill for learning from texts, international reading research consistently shows that on average 1 out of 5 students at the age 15 has not reached the basic level of reading comprehension that is required to effectively learn from texts and to function well in society (OECD, 2010, 2014, 2016). This means that these students are not sufficiently able to extract the main idea from a text, to understand relations between parts of texts and/or to link information in a text to background knowledge or personal experiences (OECD, 2016). That is, these students are not able to learn from a text because they do not succeed to create a complete and coherent mental model of the text they are reading (Kintsch, 1986). The alarming number of struggling readers and the fact that we have not been able to reduce this number in the last decade emphasizes the need to invest in the development of effective teaching strategies that support learning from text, not only for young children but also for adolescent readers (see Edmonds et al., 2009).

Effective teaching strategies for developing the reading comprehension skills that are essential for learning from text should contain three vital elements: (a) sustained deliberate practice (i.e., purposeful and repeated practice with texts in varying domains and genres), (b) strategy instruction (i.e., guidance and information on how to select and use appropriate and effective reading strategies during reading), and (c) individual feedback (i.e., tailored to the needs of the individual reader; Crossley & McNamara, 2017). There is a large base of literature on effective reading programs that are aimed at teaching readers strategies in general for better reading comprehension (for reviews, see e.g., Dole et al., 1991; Fuchs & Fuchs, 2005; Paris & Jacobs, 1984; Slavin et al., 2008, 2009). Another line of research in the scientific literature on reading comprehension is focused on supporting learning from text 'on the job'. That is, students are for example given comprehension questions during or directly after reading a text and receive individual feedback on their answers in order to facilitate learning from text (see e.g., Kulhavy, 1977). Providing students constantly with individual feedback is a time consuming activity for which teachers often do not have enough time. Information and computer technologies might provide possibilities to deliver personalized instruction and feedback to children and students while reading to optimize learning from text (e.g., Nielen et al., 2017).

Decades of research have shown the positive effects of feedback on learning performance (e.g., Azevedo & Bernard, 1995; Hattie 2012; Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Kulhavy, 1977; Shute, 2008; van der Kleij et al., 2012, 2015). Additionally, based on more than 900 meta-analyses on schooling effects, Hattie (2012) concluded that feedback is one of the top-10 positive influences on learning, even though studies on the effects of feedback show very much variability. This variability not only concerns the magnitude of the reported effects of feedback among studies, but also the ways in which feedback is provided to students. In line with these review studies, we consider feedback as individualized information that is communicated to the reader in response to the reader's performance (e.g., answers on comprehension questions or words that have to be filled in while reading a text) with the intention to enhance learning. It is important to get a better understanding of how providing feedback might help or obstruct learning from text because most learning in schools is still the result of understanding the information that is presented in written form.

According to the *Feedback Intervention Theory* of Kluger and DeNisi (1996), the effect of feedback may depend on the task or skill targeted by the feedback, the design of the feedback, and other situational variables (i.e., personality or methodological variables). Contrary to previous review studies in which the effects of feedback on a broad range of targeted tasks and skills were investigated qualitatively (e.g., Jaehnig & Miller, 2007) and quantitatively (e.g., Kluger & DeNisi, 1996; Shute, 2008), the present quantitative meta-analysis has a narrower scope, investigating the effects of feedback specifically targeted at learning from text. In the included studies the feedback was given during or after the reading task. Studies on reading programs of which feedback was only an integral part, like reciprocal teaching, tutorial dialogues or reading with the help of (voluntary) reading tutors were outside the scope of the present meta-analysis (e.g., see Palinscar & Brown, 1984). To better understand when and why feedback is or is not effective to support learning from text we tested the impact of three feedback design variables: (a) timing of the feedback, (b) type of feedback and (c) the means of providing feedback to the reader. The third type of variables mentioned by Kluger and DeNisi (1996), situational variables (i.e., personality variables and methodological variables), are taken into account when checking the results of the meta-analysis for possible biases (e.g., age group of the participants, instructional design of the texts that were read in the studies, random assignment of participants to conditions, experimental design of the studies).

Timing of Feedback

Although feedback appears to be a vital element that supports learning from text, the scientific literature differs on the optimal timing for providing feedback. In previous studies the focus regarding the issue of timing of feedback has mainly been on the comparison of immediate feedback (i.e., during or right after a learning task) versus delayed feedback (i.e., feedback provided some hours or days after the learning task; Dempsey & Wager, 1988; Hattie & Timperley, 2007; Metcalfe et al., 2009; Mory, 2004; Shute, 2008). In the present study we take a new approach to look at differences in timing of feedback, namely by comparing two forms of immediate feedback: feedback that is provided on student responses to questions or tasks during reading (i.e., after reading segments of a text) and feedback that is provided on student responses to questions or tasks directly after reading (i.e., after finishing a whole text). Some studies show positive effects on learning from text if feedback is provided during reading (e.g., Llorens et al., 2014) whereas other studies show no effect (e.g., Farragher & Yore, 1977) or detrimental effects of feedback on learning from text (e.g., Fernald & Jordon, 1991). Similarly, results are mixed among studies in which the effects of feedback directly after reading on learning from text are tested (e.g., Adams & Strickland, 2012; Butler et al., 2013; Saunders, 1998).

From a theoretical point of view, one could argue for both: providing feedback during reading and/or providing feedback directly after reading to support learning from text. Feedback could best be provided during reading based on the idea that feedback helps readers to evaluate and adjust their knowledge during reading, so that flaws in understanding (i.e., an inadequate mental representation of the text) can be detected and corrected as soon as possible. From this perspective, feedback can act as scaffold for comprehension monitoring. This metacognitive skill stimulates the reader to take corrective actions in cases of flaws in understanding, which is an essential skill for learning from text (Baker & Brown, 1984). The preference for feedback during reading corresponds with the five-stage model by Bangert-Drowns et al. (1991) describing the state of a learner when receiving feedback. In the first three stages of the model the reader (1) activates knowledge, interests, goals and/or beliefs about self-efficacy, (2) applies search and retrieval strategies that are activated by a question or task, and (3) gives a response to a question or task. According to the model, feedback follows after the response of the reader (i.e., after the third stage) and triggers the next two stages in which the reader (4) evaluates and (5) adjusts task-relevant knowledge, interests, goals or beliefs about self-efficacy. In line herewith, Mullet and Marsh (2016) formulated two guidelines which feedback has to comply to in order to effectively enhance learning: it needs to help learners (a) to notice errors and (b) to correct them as soon as possible. According to the five-stage model of Bangert-Drowns et al. (1991) and the guidelines of Mullet and Marsh (2016) feedback should thus function as a 'forget-cue' to prevent errors from persisting in memory, meaning that feedback during reading would be more effective to support learning from text as compared to feedback after reading.

From a cognitive load perspective, it is important to design feedback in a way that reduces the reader's cognitive load, in other words the information that has to be held in working memory during a task, while reading a text to enhance learning (Sweller, 1994; Sweller et al., 1998). From this perspective, one could argue for both feedback during reading and/or directly after reading. On the one hand, interrupting reading with tasks (e.g., comprehension questions or blanks in a text that have to be filled in) and subsequent feedback during reading increases the extraneous cognitive load of a reading task compared to reading a text when questions and feedback are provided directly after reading. Providing feedback during reading forces the reader to switch attention between the building of a coherent mental model of a text and the processing of the question/task and the subsequent feedback. In other words, providing feedback during reading requires the reader to multitask by switching between reading the text and executing the tasks or answering questions and processing the provided feedback (see Subrahmanyam et al., 2013). In line with this reasoning, it might be better to provide feedback directly after reading instead of during reading, so that students' limited working memory capacity can fully be deployed to create a mental model of the text (see also Kluger & DeNisi, 1996). On the other hand, questions and feedback during reading may help the reader to construct schemas of the information in the text (i.e., connecting parts of information within the text with each other or with background knowledge). By schematizing the information in the text, several pieces of information from the text can be chunked as a single element. In line with this idea, questions and feedback during reading help readers to construct these chunks of information from the text, which reduces cognitive load, and integrate them in their mental model of the text (see Paas et al., 2004).

Only one study (Peverly & Wood, 2001) on the effects of feedback on learning from text directly compared the effects of feedback during reading and feedback directly after reading within one experiment. Students from grade 9 and 11 in two feedback conditions (i.e., during and directly after reading) significantly outperformed students in the control conditions on an unstandardized reading comprehension post-test that assessed learning from texts of similar length and readability level as the stories in the intervention. Additionally, students receiving feedback during reading outperformed students who answered questions and received feedback directly after reading. No differences in performance were found on a standardized reading comprehension post-test between the feedback conditions versus the control group nor between the two feedback conditions. However, this was a small-scale study with only ten students in each condition and further research that directly compares the effects of feedback during and after reading is needed.

Different Types of Feedback

Another aspect of providing feedback that is still under debate in the scientific literature on the effects of feedback on learning from text is the issue regarding the type of feedback that would enhance learning best (see e.g., Shute, 2008). Kulhavy (1977) was one of the first researchers who reviewed studies aimed at testing the effects of feedback on learning from text. In his review, Kulhavy described that the composition of feedback can range along a "continuum from the simplest *Yes-No* format to the presentation of substantial corrective or remedial information that may extend the response content, or even add new material to it" (Kulhavy, 1977, p. 212). More than a decade later, Kulhavy and Stock (1989) argued that when studying the effects of feedback on learning from an information processing perspective, the content of a feedback message can be subdivided into two parts: *verification* and *elaboration*. Verification consists of a simple yes/no or right/wrong statement. In most studies, feedback that only includes verification is called *Knowledge-of-Response* (*KOR*; for a review see Shute, 2008). All information added to the verification statement can be seen as the elaboration part of the feedback message. According to Kulhavy and Stock (1989), the elaboration part of the feedback can include three types of information with increasing complexity: task-specific information (i.e., the correct answer), instruction-based information (e.g., explaining why an answer is correct or repeating the part of a text that contained information regarding the correct answer) and extra-instructional information (i.e., providing information, examples or analogies that were not present in the original learning material) respectively. When the verification part of the feedback is elaborated with the correct answer, the feedback message is often referred to as *Knowledge-of-Correct-Response* (*KCR*). Feedback that additionally includes instruction-based or extra-instructional information is often referred to as *Elaborated Feedback (EF)*. Kluger and DeNisi (1996) referred to the different amounts of information included in a feedback message as feedback specificity. More than a decade after the first review of studies on the effects of feedback by Kulhavy (1977), Kulhavy and Stock (1989) still had to conclude that studies on the effects of different types of feedback on learning from text showed inconsistent results. Also, researchers of more recent review studies on the effects of feedback on learning came to the same conclusion (e.g., Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Mory, 2004; Shute, 2008; van der Kleij et al., 2015).

The inconsistent results on the effects of different types of feedback on learning from text found in the existing literature may relate to differences in the focus of the provided feedback. Hattie and Timperley (2007) argued for instance that feedback can work at four different levels: task level (focused on how well a task is performed), process level (focused on the strategies that are needed to perform a task), self-regulation level (e.g., focused on self-evaluation or comprehension monitoring), and self-level (usually praise; see also Hattie, 2012). Hattie and Timperley (2007) described KOR and KCR as being task level feedback, that would be effective for building surface knowledge, whereas elaborated feedback (EF), which includes information on the process or self-regulation level, would be especially effective in enhancing deep processing of information. In line with this reasoning, van der Kleij et al. (2012) argued in a meta-analysis on the effects of feedback on learning in computer-based environments that providing EF was particularly effective for promoting higher-order information processing that requires not only literal recall of information, but also making inferences or transfer of knowledge. Based on the idea that learning from text is a form of higher-order information processing that goes beyond building surface knowledge such as storing facts (e.g., Craik & Lockhart, 1972), one would expect EF, compared to KOR or KCR, to be especially effective in enhancing learning from text. In contrast to this expectation however, in many recent studies in which the effects of different types of feedback were compared no differences were found in the effects of more or less elaborate feedback on learning from text (Golke et al. 2015; Llorens et al. 2014). Butler et al. (2013) further studied this unexpected lack of effect of EF by including different assessment levels for testing the effect of EF versus KCR. They showed that, compared to KCR, EF better enabled the students to answer inference questions. On a comprehension post-test assessing more superficial knowledge of the texts (i.e., definition questions) EF was not more effective than KCR in supporting learning from text. We hypothesize therefore that EF is especially effective when deep processing is required and that KCR is as effective for information processing on a surface level (see Graesser et al., 1997).

Means of Providing Feedback

Next to the timing and type of feedback, studies on the effects of feedback on learning from text also differ in the means of providing feedback to the reader. The emergence of computer-applications for reading instruction creates a wealth of possibilities to provide computer-delivered feedback during or directly after reading. Feedback can not only be provided using multiple modalities (e.g., text, audio, visuals or a tutor on screen), but also in a spatially and temporally integrated format. In other words, after answering a question or completing a task, the reader is only a mouse-click away from the feedback appearing on the screen. However, also before the computer era researchers have studied the effects of feedback on learning from text. In these early studies (e.g., Farragher & Yore, 1997; Feldhusen & Birt, 1962) feedback was non-computer-delivered, requiring participants to actively uncover the feedback messages themselves (for example removing a sticker that covers the feedback). The effects of non-computer-delivered feedback on learning from text found in these early studies are mixed. For example, in a study of Feldhusen and Birt (1962) college students read texts about teaching machines and programming language and had to fill in words in blanks in these texts during reading. Students had to check each answer by comparing their response to the answer on a feedback flap that was stored away in a separate folder. Students learned more from the text when they had to look at the feedback after each answer compared to a condition in which they had to fill in blanks during reading, but were not provided with feedback. Farragher and Yore (1997) performed a study in which 9th grade students read a text on environmental science and were asked a question after every 20 sentences. Students had to check their answers by using latent image pens that uncovered feedback responses that were printed with invisible ink. However, no effects of feedback were found on learning from the text. More recently, Clariana and Koul (2006) used a comparable approach; 10th and 11th grade students read expository science texts and had to answer questions during reading. After answering a question, students had to scratch a blue dot (like scratch-off lottery tickets) to make the correct answer visible. Students in feedback conditions outperformed students in a no feedback-condition on a comprehension post-test that assessed how much students had learned from the texts.

In a study of Lasoff (1981) a comparison was made between non-computer-delivered feedback and computer-delivered feedback. University students read five texts about programming language and answered multiple choice questions during reading. One group of students read the texts, answered questions and received feedback on separate sheets of paper and one group of students read the texts and answered the questions on the computer and also received computer-delivered feedback on their answers. The feedback in both conditions included the correct answer and explanations of why an answer was correct or hints when the answer was incorrect, so that the student could try again. No differences in learning were found between the feedback and no feedback conditions and no difference was found between the group that was provided with non-computer-delivered feedback and the group that was provided with computer-delivered feedback. However, this was a small-scale study with only ten to twelve students in each condition and more research is needed in which the effects of non-computer-delivered feedback and computer-delivered feedback is systematically compared.

Although there is a wide range of means of providing feedback, the cognitive load theory may help to predict which means will be most effective. That is, apart from the complexity of the text, extraneous factors such as the means of providing feedback are of influence on the overall cognitive load of the reading task (Sweller et al., 1998). According to the split-attention effect, working memory is challenged less when information is presented in a spatially and temporally integrated rather than in a separated format (e.g., Florax & Ploetzner, 2010). In line with this perspective, we hypothesize that computer-delivered feedback can more easily meet these requirements compared to non-computer-delivered and is, therefore, more effective in supporting learning from text.

Present Study

The aim of the present meta-analysis is to examine the effects of feedback on learning from text in conventional readers. In line with previous meta-analyses on the effects of feedback on learning (e.g., Azevedo & Bernard, 1995; Hattie 2012; Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Kulhavy, 1977; Shute, 2008; van der Kleij et al., 2015), we expected to find a positive effect of feedback on learning from text. In order to explain differences in the effects of feedback in previous studies, we investigated three characteristics of feedback related to design of the feedback: (1) timing of feedback, (2) types of feedback, and (3) the means by which feedback is provided to the reader. Regarding the effects of the timing of feedback, in line with the idea that feedback during reading helps the reader to chunk information (Paas et al., 2004) one could expect feedback during reading to be more effective. On the other hand, if feedback during reading appears to increase the cognitive load, because the reader has to multitask between reading and understanding the text and answering questions and processing feedback, than feedback that is provided directly after reading could be more effective to support learning from text (Subrahmanyam et al., 2013). Regarding the different types of the feedback, we expect more extensive forms of feedback, like elaborated feedback (EF) to be more effective than simple forms of feedback, like knowledge-of-response feedback (KOR), to support learning from text. We expected EF to be particularly effective when deep information processing is required for answering the questions about a text. Additionally, because it takes more effort and time, and therefore working memory capacity, to process non-computer-delivered feedback we expect, in line with the split attention hypothesis, computer-delivered feedback to be more effective in supporting learning from text than non-computer-delivered feedback.

Method

Inclusion and Exclusion Criteria

In line with previous review studies on the effects of feedback on learning (e.g., Kluger & DeNisi, 1996; Shute 2008; van der Kleij et al., 2015), we defined feedback as item-based individualized information that is communicated in *reaction* to the readers' response with the intention to enhance learning from the text. In the present study we looked at feedback that was provided during reading or directly after reading a text, concerning the reader's performance (i.e., answer to a question). Interactive options in a text that did not include information that reflects the individual performance of the reader, like providing pronunciation or glossary options were not considered as feedback (e.g., Davidson & Noyes, 1995). Additionally, feedback had to be systematically provided to the reader as opposed to incidentally whereby the methods of delivering feedback may differ (e.g., computer-delivered feedback, see Llorens et al, 2014; answers and/or hints masked with chemical ink, a flap or sticker, see Farragher & Yore, 1997 and Feldhusen & Birt, 1962; or separate answer sheets inserted in workbooks, see Clariana & Koul, 2006).

Studies on the effects of interventions of which feedback was only an integral part, like reciprocal teaching, tutorial dialogues or reading with the help of (voluntary) reading tutors were excluded from the meta-analysis. Studies were also excluded if feedback was already visible before answering questions or completing tasks, because in these cases feedback was not given in reaction of the reader's response (e.g., the copying condition in Anderson et al., 1972), if participants had to read in pairs or small groups and received the feedback per group of participants instead of individual feedback (e.g., MacGregor, 1988), or if participants had the option to turn off the feedback (e.g., Mikulecky, 1987).

In addition to the operational definition of feedback described above, studies were included in the meta-analysis if the following criteria were met:

(a) An intervention study had to be described, either using a between-subjects or within-subjects design, and a comparison had to be made between a feedback condition and a comparison condition.
(b) In the feedback condition, participants received feedback during reading or directly after reading a text.
(c) Participants in the control condition had to read a similar or comparable text, but without receiving feedback.
(d) The reading task had to concern reading narrative or informative texts, not lists of words or separate sentences. The texts could be accompanied by pictures or video-content.
(e) The text had to be read by participants themselves (requiring them to be conventional readers), not read to them by a computer or adult.
(f) At least one outcome measure of learning from text had to be reported. Learning from text could be measured using comprehension questions, recall or retelling tasks or tasks targeted at ordering text elements or pictures.
(g) Participants had no mental, physical, or sensory handicaps and were conventional readers.
(h) Reports of the studies had to be written in English.
(i) A sufficient amount of statistical information had to be reported to calculate effect sizes for the outcome measures that are relevant for the present meta-analysis.

Outcome measures for learning from text were included in the present meta-analysis if learning of information from the text(s) read during the intervention was assessed using comprehension questions (e.g., criterion test used in Anderson et al., 1972) or recall tasks (e.g., cued recall test used in Kealy & Ritzhaupt, 1962). Also, outcome measures for learning from new texts that were read as a part of a reading comprehension post-test were included (e.g., accuracy in answering comprehension questions about a text read in the final phase, which was different from the ones read in the training phase, in Llorens et al., 2014). Both measures developed by the researchers (e.g., achievement test used in Lasoff, 1981; comprehension questions used in Llorens et al, 2014) as well as standardized reading comprehension tests in which participants had to answer comprehension questions about texts they had to read during the test (e.g., Expository Text Comprehension Test and the Narrative Text Comprehension Test used in Sung et al., 2008) were included in the meta-analysis.

No restrictions were set for the inclusion of studies in the meta-analysis regarding the participant's age, country or origin, publication status or publication date of the reports of the studies. However, studies were excluded if the described samples or data overlapped with those of other studies in the meta-analysis (e.g., Wijekumar et al., 2013).

Search Strategies

To obtain eligible studies seven databases (PsycInfo, PsycArticles, ERIC, Proquest Dissertations and Theses Global, Web of Science, Linguistic and Language Behavior Abstracts and Google Scholar) were searched online up to March 2017 for journal articles, reports, conference proceedings, books, book chapters and dissertations describing studies investigating the effects of feedback on learning from text. Several combinations of search terms were used referring to books, e-books, literacy and reading on the one hand, and feedback, scaffolding, interactivity and tutoring on the other hand (see Appendix A for the exact search terms). Additionally, the reference lists of relevant handbooks on literacy, reading and technology (see Appendix B for an overview of searched handbooks) and review papers that came up in the online search were checked for studies to include in the meta-analysis. Subsequently, publication records of authors of papers that were found eligible for the meta-analysis were checked using Google Scholar. Over 15,000 (duplicates excluded) references and abstracts were checked for eligibility by the first and second author, of which 419 reports were checked in full-text. The described search strategies resulted in 60 eligible reports. For an overview of the search steps and the corresponding numbers of checked articles, see the PRISMA diagram in Appendix C.

Coding Procedures

The following information was coded: (a) bibliographical information (e.g., authors; year and title of the study; type of publication; country in which the study was performed), (b) study sample (number of participants in each condition and being primary school students, secondary school students or university students), (c) assignment of participants to conditions (randomization on individual level or not) (d) number of intervention sessions, (e) text characteristics (narrative or informative; text only, text and pictures or text and video or animations; text order being linear or not), (f) feedback characteristics (timing of the feedback, type of feedback, means of providing feedback), (g) type of outcome measures (direct post-test or delayed post-test; multiple choice questions, open questions, recall/retelling tasks, ordering pictures or text elements), and (h) information processing level that was aimed at in the outcome measures (factual knowledge versus inferential knowledge). Timing of feedback was coded as during reading or directly after reading. The type of feedback was coded in the following three categories: knowledge-of-response (KOR), knowledge-of-correct-response (KCR) or elaborated feedback (EF). The means of providing feedback was coded in two categories: computer-delivered feedback and non-computer-delivered feedback.

All studies were coded by the first author and undergraduate students in Education and Child studies, who worked in pairs and were trained in coding beforehand by the first author. Two students coded the same report and had to reach consensus on each coding category. Inter-coder reliability was calculated between the scores that the two undergraduate students agreed on and those of the first author. Inter-coder reliability was on average $\kappa = .77$ ($SD = .13$), ranging from $\kappa = .58$ for timing of feedback to $\kappa = 1.00$ for the number of intervention sessions and delayed post-test measures. In case of disagreements, the first author searched through the intervention reports an extra time and made a final coding decision. If essential information on the intervention was not reported, we looked up the software on the Internet (in cases where the used software was available online), and/or we tried to contact the authors by email (in case of reports that were published less than 10 years ago, i.e., published after 2009). Also, if reports did not include sufficient statistical information, we tried to contact authors for studies that were published after 2007. We excluded older studies that did not include sufficient statistical information and/or treated missing information on the interventions as missing data.

If results were reported for subgroups of participants, we separately coded each contrast with the corresponding control group and calculated effect sizes for the different subgroups. If a study included several feedback conditions, we also separately coded each contrast with the corresponding control condition and calculated effect sizes for the different feedback conditions. If a study included one control group and more than one eligible feedback condition, we divided the number of participants in the control group by the number of feedback conditions to prevent us from including the same participants from the control group more than once in the analyses (for a similar approach see Takacs et al., 2014, 2015; Mol et al., 2008, 2009). One feedback condition was chosen in studies where splitting the control group resulted in a group of less than 10 participants. In these cases, the most elaborate feedback condition was included in the meta-analysis (e.g., the KCR condition in Adams & Strickland, 2012).

Statistical Methods

The dependent variable in the present meta-analysis was the difference in mean scores on learning from text between the feedback condition and the control condition. In order to standardize for the use of different scales and types of outcome measures and to correct for possible biases due to the small sample sizes in most of the primary studies, Hedges' g was calculated for the difference between these two conditions. A positive effect size indicated that the participants in the feedback condition performed better on learning from text than participants in the control condition. If available, raw means and standard deviations of the post-test scores and, if applicable, delayed post-test scores were used to calculate Hedges' g. However, if these weren't available, gain scores, frequency distributions, t-test statistics or F-statistics were used to calculate Hedges' g. Comprehensive Meta-Analysis software, Version 2.0 (Borenstein et al., 2005) was used to calculate the effect sizes and for further meta-analytical procedures. Effect sizes for all measurement instruments and tasks were inspected for outliers (i.e., effect sizes with a standardized residual exceeding ± 3.29; Tabachnick & Fidell, 2007). In case of the presence of outliers, these were winsorized into a value .001 higher or lower than the highest or lowest non-outlying effect size. In case of more than one outlier per outcome measure, the rank order of effect sizes was maintained by adding .001 to each next outlier. Subsequently, to account for dependency among multiple effect sizes within a study, if two or more outcome measures for learning were reported in a study, the effect sizes for these different outcome measures were averaged.

In order to take into account the heterogeneity in interventions, study designs and study samples among the studies included in the present meta-analysis, the random effects model was used for combining the effect sizes of different studies and to calculate the 95% confidence intervals of the combined effects (Borenstein et al., 2009; Lipsey & Wilson, 2001; Raudenbush, 2009; Viechtbauer, 2007). When combining the effect sizes for different studies, effect sizes were weighted by their inverse variance, so that studies with larger samples and smaller standard errors had a greater weight on the mean effect size (Lipsey & Wilson, 2001; Shadish & Haddock, 2009). Heterogeneity of effect size was estimated based on the Q-statistic, with a significant Q indicating that the variability among effect sizes was larger than may be expected based on sampling error only (Lipsey & Wilson, 2001).

To investigate the robustness of the effect of feedback on learning from text, we used three indicators for the presence of publication bias in our data. First, we checked our results for publication bias graphically by inspecting the funnel plot with the effects of feedback on learning from text for all studies. Asymmetry in this plot could indicate publication bias, the overrepresentation of significant and large effects in the literature, because those are more likely to get published (Borenstein et al., 2009). In case of publication bias, Duval and Tweedie's (2000) Trim and Fill procedure was used to adjust for this publication bias. Second, we checked the classic fail-safe *N* to investigate how many null-effects would be needed to turn a significant effect into a non-significant one. In line with Rosenthal's criterion (Rosenthal, 1979), we considered an effect robust if the fail-safe *N* exceeded $5k + 10$ (with k representing the number of study contrasts). Third, we checked how many effect sizes would be required according to Orwin's fail-safe *N* to reduce the combined effect to a value lower than 0.01 (Orwin, 1983; for a similar procedure see Davis, 2018).

To answer our research questions, moderator analyses were performed using the random effects model to test for differences between the effects of timing of feedback, different types of feedback and the means by which feedback was provided to the reader. Regarding the small number of studies in some categories ($k < 20$) and the fact that studies are not equally distributed among categories, a random effect model was used that assumed a common among-studies variance component (Rubio-Aparicio et al., 2017). Only variables that included at least four contrasts in each cell were used for moderator analyses. A moderator was considered significant if the $Q_{between}(df)$ statistic was significant.

Results

Descriptive Analyses

The literature search for the present meta-analysis resulted in 60 studies, published between 1962 and 2016 (see Appendix D for references to all publications). The studies contained 104 contrasts of reading with feedback conditions versus control conditions of reading without receiving feedback. One contrast was described in a technical report, eight contrasts in conference proceedings, 21 contrasts in dissertations and 74 contrasts in journal articles. The majority of the contrasts, 85, were conducted in the USA, six contrasts were conducted in Germany, five in Spain, four in Taiwan, two in Canada, one in Iran and one in the UK. In twelve of the contrasts participants were not assigned randomly to conditions or random assignment was performed on classroom/group level, in the remaining 92 contrasts participants were randomly assigned to conditions. The contrasts included a total of 178 effects of feedback on outcome measures for learning from text, ranging from -0.91 to 2.41. All contrasts and effects are shown in Appendix E. In total 6,124 participants, ranging from primary school children to university students, were included in the contrasts. The average sample size per contrast was 59.46 (*SD* = 48,64). Information about the level of information processing (factual or inferential knowledge, i.e., superficial or deep level information processing) at which the questions in the immediate and delayed post-tests were targeted was hardly ever reported, which made it impossible to code this information and include it in the present meta-analysis.

Inspection of all effect sizes showed three outlying positive effects for learning from text. These effect sizes were winsorized into a value of respectively 0.001, 0.002 and 0.003 higher than the highest non-outlying effect size in order to maintain the rank order of effect sizes.

The Effect of Feedback on Learning From Text

To investigate the effect of feedback on learning from text, we combined the effect sizes for all contrasts, resulting in an average effect of $g+ = 0.35$ ($k = 104$, $SE = 0.05$, 95% CI = [0.25, 0.46], $p < .001$). Feedback had a positive effect on learning from text. To test the reliability of the overall effect of feedback, we inspected for publication bias and the robustness of the effect. The funnel plot used to inspect for publication bias showed a symmetric pattern of effect sizes and Duval and Tweedie's trim and fill procedure indicated that no extra studies had to be imputed to obtain a symmetric distribution of effects. Additionally, the classic fail-safe *N* indicated that 3,662 contrasts with a null-effect would be needed to turn the significant effect of feedback on learning from text into a non-significant one. According to Orwin's fail-safe *N*, 2,818 contrasts with a null-effect would be needed to reduce the overall effect size to a value lower than 0.01. Based on these statistics, we concluded that the effect of feedback on learning from text was reliable and robust.

To test for other possible biases, moderator analyses were performed for country, assignment of participants to conditions (random on an individual level vs. not random or random on classroom/group level), subject design (within vs. between), text type (narrative, informative or both), instructional design (text only, text + pictures or text + video/animations), type of outcome measure (open question, MC-questions or both) and subject's age group (elementary school, secondary school, students) and meta-regression analyses were performed for publication year, frequency of feedback relative to text length and the number of intervention sessions. Except for subject design and age group, none of the regression models or moderators were significant. On average, studies with a within-subject design showed a larger effect of feedback on learning from text ($g+ = 0.93$, $k = 4$, $SE = 0.26$, 95% CI = [0.41, 1.45], $p < .001$) than studies with a between-subject design ($g+ = 0.33$, $k = 100$, $SE = 0.05$, 95% CI = [0.23, 0.43], $p < .001$), $Q_{between}(1) = 4.95$, $p = .03$. However, only four contrasts came from within subject studies, so we did not take this difference into account in further analyses. For age group, we found a significant difference in effects in studies from different age populations, $Q_{between}(2) = 14.54$, $p = .001$. Neither for elementary school students ($g+ = 0.32$, $k = 5$, $SE = 0.23$, 95% CI = [-.12, 0.76], $p = .16$) nor for secondary school children ($g+ = 0.09$, $k = 34$, $SE = 0.09$, 95% CI = [-0.09, 0.26], $p = .32$) we found a significant effect of feedback on learning from text. For university students however, there was a significant positive effect of feedback ($g+ = 0.50$, $k = 65$, $SE = 0.07$, 95% CI = [0.37, 0.63], $p < .001$). A significantly larger proportion of the studies with secondary school students (79.1%) used feedback during reading in the interventions than was the case for the studies with university students (61.5%, $\chi^2 = 3.80$, $p = .05$) which might explain the lack of effect but other explanations might hold as well which will be elaborated on in the discussion. In order to increase power to conduct the proposed moderator analysis, the low number of studies with primary school students, and to maintain the focus of the present meta-analysis on variables regarding the design of the feedback, results will not be separately reported for the three age groups.

For post-tests of learning from text that were applied immediately after the intervention was completed, the average effect of feedback was $g+ = 0.32$ ($k = 102$, $SE = 0.05$, 95% CI = [0.22, 0.41], $p < .001$), for delayed post-test measures the average effect was $g+ = 0.30$ ($k = 23$, $SE = 0.14$, 95% CI = [0.04, 0.57], $p = .03$). Time between the interventions and delayed post-test measures varied from one to ten weeks. Because for most of the study contrasts (77.9%) only immediate post-test scores were reported, we conducted further analyses only on the immediate post-test scores of learning from text. As the effect of feedback on immediate post-tests was heterogeneous ($Q(101) = 324.78$, $p < .001$), we conducted moderator analyses to test for differences in the effects of feedback concerning feedback timing, types of feedback and the means by which feedback was provided.

Timing of Feedback

For two contrasts, the reports did not provide enough information to determine if feedback was provided to participants during reading or directly after reading the text. Out of the remaining hundred contrasts, in 69 studies the effect of feedback during reading and 31 the effect of feedback directly after reading on learning from text was tested. Moderator analysis showed that feedback directly after reading ($g+ = 0.46$, $k = 31$, $SE = 0.09$, 95% CI = [0.28, 0.64], $p < .001$) was more effective in enhancing learning from text than feedback during reading ($g+ = 0.23$, $k = 69$, $SE = 0.06$, 95% CI = [0.11, 0.34], $p < .001$), $Q_{between}(1) = 4.32$, $p = .04$ (see Table 1). Both the effects of feedback during reading and feedback directly after reading on learning from text were heterogeneous (see Table 1). Therefore, moderator analyses for the effects of different types of feedback were performed for contrasts studying feedback during reading and directly after reading separately.

Different Types of Feedback

Feedback Directly After Reading

A moderator analysis showed that feedback type was a significant moderator of the effect of feedback on learning from text ($Q_{between}$ (2) = 7.38, p = .03), see Table 2 and Figure 1. If provided directly after reading, elaborate feedback (EF), showed the largest positive effect on learning from text ($g+$ = 0.92, k = 6, SE = 0.25, 95% CI = [0.42, 1.42], p < .001). Knowledge-of-correct-response feedback (KCR) had a moderate positive effect on learning from text ($g+$ = 0.61, k = 13, SE = 0.18, 95% CI = [0.27, 0.96], p < .001). Knowledge-of-response feedback (KOR) had no significant effect on learning from text ($g+$ = 0.14, k = 12, SE = 0.18, 95% CI = [-0.21, 0.48], p = .45). All effects were heterogeneous. The difference in effects between EF and KCR did not reach significance ($Q_{between}$ (1) = 0.74, p = .39), but EF was more effective than KOR in enhancing learning from text ($Q_{between}$ (1) = 8.63, p = .003). Also, KCR was more effective than KOR ($Q_{between}$ (1) = 4.21, p = .04).

Feedback During Reading

A moderator analysis on feedback type for contrasts testing the effects of feedback during reading on learning from text showed that the effects of different types of feedback did not differ significantly from each other ($Q_{between}$ (3) = 2.86, p = .41), see Table 2 and Figure 1. Elaborate feedback had a positive, small, and significant effect on learning from text ($g+$ = 0.25, k = 24, SE = 0.25, 95% CI = [0.08, 0.42], p < .01), as did feedback containing KOR ($g+$ = 0.39, k = 11, SE = 0.39, 95% CI = [0.14, 0.64], p < .01). Neither feedback containing KCR (g+ = 0.14, k = 30, SE = 0.14, 95% CI = [-0.02, 0.30], p = .08) nor feedback that alternately contained KOR and KCR in the same study (g+ = 0.22, k = 4, SE = 0.22, 95% CI = [-0.20, 0.64], p = .31) had a significant effect on learning from text. All effects were heterogeneous.

Means of Providing Feedback

Feedback Directly After Reading

Non-computer-delivered feedback after reading did not have a significant effect on learning from text ($g+$ = 0.19, k = 8, SE = 0.24, 95% CI = -0.27, 0.65], p = .42). Computer-delivered feedback had a medium positive effect on learning from text ($g+$ = 0.59, k = 23, SE = 0.14, 95% CI = 0.32, 0.85], p < .001). This effect was heterogeneous (see Table 3). The difference between the two means of providing feedback was not significant ($Q_{between}$ (1) = 2.15, p = .14).

Feedback During Reading

Non-computer-delivered feedback during reading did not have a significant effect on learning from text ($g+ = 0.10$, $k = 28$, $SE = 0.08$, 95% CI = [-0.07, 0.26], $p = .24$), but computer-delivered feedback had a small significant effect on learning from text ($g+ = 0.30$, $k = 41$, $SE = 0.07$, 95% CI = [0.18, 0.43], $p < .001$). Both effects were heterogeneous (see Table 3). The difference between the two means of providing feedback was marginally significant ($Q_{between} = 3.78$, $p = .05$).

Discussion

The aim of the present study was to investigate the effects of feedback on learning from text in conventional readers. Based on the 104 contrasts included in the meta-analysis it can be concluded that feedback positively influences learning from text. However, the magnitude of the effect of feedback on learning from text ($g+ = 0.35$; $d = 0.36$) is smaller than the effects of feedback found in most of the previous meta-analyses on the effects of feedback on learning in general (e.g., Kluger & DeNisi, 1996; $d = 0.41$; Azevedo & Bernard, 1995; $d = 0.80$; Hattie, 2012; $d = 0.79$). Van der Kleij et al. (2015) concluded in their meta-analysis on the effects of feedback in computer-based learning environments that feedback was particularly effective for promoting mathematics performance or problem-solving skills, noting that feedback in these subject areas was mostly elaborate feedback, compared to instruction in social sciences and language, subject areas in which feedback was more often KOR- of KCR-feedback. The variation in the types of feedback included in the present meta-analysis could explain why the average effect we found in the present meta-analysis is lower. Another explanation for the lower average effect of feedback on learning from text compared to the effects found in other meta-analyses may be based on the mode of presentation of the feedback. According to the dual coding theory (Clark & Paivio, 1991), information can be processed in two different modes; verbal and non-verbal. Information in one mode can only be processed sequentially, information in two modes can be processed in parallel or simultaneously and these two modes can form interconnections which may strengthen information processing. Although Shute (2008) advised, based on her meta-analysis on the effects of feedback on learning, to use multiple modes (i.e., an audio and a visual mode; see also Clark & Paivio, 1991) for the presentation of feedback to prevent creating a cognitive overload due to modality effects (i.e., presenting both the learning material and feedback in the same modality; see also Moreno & Mayer, 1999), in the present meta-analyses in almost all studies (96.2%) feedback was presented only as text. In other words, presenting both the text and feedback in the same mode (i.e., both as written text) increases the cognitive load of the reading task, which may explain the difference between the effects of feedback on learning from text found in the present meta-analysis and the effects of feedback on more general outcomes found in previous meta-analyses.

The effect of feedback on learning from text found in the present meta-analysis was heterogeneous. The broad range of effect sizes found in the primary studies included in the present meta-analysis is in line with Hattie's (2012) conclusion that feedback on average has a positive influence on learning, but that much variation exists between studies. In order to explain the variation in effects among studies, we looked at three characteristics of the design of the feedback provided in the primary studies: (a) timing of feedback, (b) different types of feedback and (c) the means of providing feedback.

Timing of Feedback

The present meta-analysis shows that feedback is most effective to support learning from text if provided directly after reading, instead of during reading. This finding is in line with Sweller's (1994) cognitive load perspective and the results of a study by Subrahmanyam et al. (2013) showing that multitasking results in less efficient processing of a text. In line with this idea, Shute (2008) previously formulated a guideline for designing feedback to enhance learning, stating that feedback should not interrupt the learner when he or she is actively engaged in a task, because this could impede learning. As we might infer from the results of the present-meta-analysis, feedback during reading seems to interrupt the natural reading process and forces the reader to multitask between the processing of the text and the questions or tasks and subsequent feedback during the text thus placing extra load on working memory, also called the split-attention effect (Sweller, 1994). This conclusion is comparable to that of a recent meta-analysis on the effect of technology-enhanced storybooks for young children, who were not conventional readers, showing that interactive options in an e-book do not promote comprehension of the story, but seem to distract children from the storyline (Takacs et al., 2015). From the present meta-analysis it appears that even for conventional readers interaction during reading seems to impede learning from a text, even if this interaction is relevant to understand the information in the text, which is not the case in most interactions in technology-enhanced storybooks for young children. According to Sweller et al. (1998), one could argue that providing feedback results in an increased interactivity between elements (i.e., information from the text, the questions or tasks and the feedback) that has to be processed, which results in an increased cognitive load. As a consequence, less working memory capacity is available to integrate the information into a coherent mental model of the text, which impedes learning from the text.

Brangert-Drowns et al. (1991) proposed in their five-stage model of the effects of feedback on learning that feedback should trigger the reader to evaluate and adjust task-relevant knowledge. It seems that, in contrast to the guidelines of Mullet and Marsh (2016) stating that feedback should function as a 'forget-cue', the best moment for reflecting on task-relevant knowledge (i.e., a reader's mental model of the text), is not necessarily directly after a possible error occurred. The present meta-analysis showed that it is more effective to first build a complete mental model of a text and subsequently evaluate and adjust the mental model based on questions or tasks followed by feedback after the text. The increased cognitive load caused by questions and feedback during reading appears to interfere with the construction of a mental model of the text.

The finding that feedback during reading less effectively facilitates the evaluation and adjustment of the reader's mental model of a text than feedback after reading also fits the *imperfect mental model view* of Chi (2000). Chi states that, as a consequence of differences in readers' pre-existing mental models that are based on individuals' background knowledge and experience, the way and pace at which readers build mental models of sentences or parts of a text and detect possible flaws in the mental model are not the same for everyone. In line with this reasoning, the moment at which a question or task and subsequent feedback regarding a specific part of the text could be most helpful differs per reader. Providing questions or tasks and feedback at the end of a text enables readers to first engage in reading and mental model building in their own pace and manner. Subsequently, feedback can help the reader to revise the mental model where needed based on the information provided in the feedback messages.

Different Types of Feedback

The amount of information that feedback messages contain also appears to influence the effect that feedback has on learning from text. As a consequence of the aforementioned differences in the effects of timing of feedback, we investigated the effects of different types of feedback separately for feedback provided during and feedback provided directly after reading. If provided after reading, EF and KCR appeared to be most effective, more so than KOR, in promoting learning from text. Although the largest effect was found for EF ($g+ = 0.92$), this was not significantly different from the effect of KCR on learning from text ($g+ = 0.61$). This is possibly due to the low number of studies containing elaborate feedback ($k = 6$), which reduces the statistical power of the comparison. The large positive effect of EF on learning from text is in line with the results of previous meta-analyses showing that elaborated feedback is particularly effective for promoting higher order learning tasks and deep learning (Hattie & Timperley, 2007; Jaehnig & Miller, 2007; van der Kleij et al., 2015). As described in the model of Kulhavy and Stock (1989) an elaborate feedback message not only contains verification, but also the correct answer and some instructional information (e.g., explaining why an answer is correct or repeating the part of a text that contained information regarding the correct answer) or extra-instructional information (e.g., providing information, examples or analogies that were not present in the original learning material). This instructional- or extra-instructional information can help the reader to better process and understand the learning material by helping the reader to improve the interconnections between the building blocks of the mental model instead of only knowing that the mental model is correct or incorrect, which is in fact the only message in KOR or (to a lesser degree) in KCR (see also Hattie & Timperley, 2007). In line herewith, Kluger and DeNisi (1996) stated in their Feedback Intervention Theory (FIT) that the extra information in the feedback message provides the learner with guidance on how to invest additional effort to succeed in task performance: in the case of learning from text to reach or restore completeness and coherence of the mental representation of the text.

For studies in which feedback was provided during reading, no differences were found between the different types of feedback. So, although it appears to be most effective to provide elaborated feedback after reading, during reading only stating if an answer was correct or not appeared to be as effective as elaborate feedback. This contrast could possibly be explained by the idea that feedback during reading hinders the natural reading process, and, therefore, the building of a mental model of the text. Although elaborate feedback contains more information than KOR, it takes more time and effort to process an elaborate feedback message than a simple *right* or *wrong*. In other words, the extraneous cognitive load (Sweller, 1994) of an elaborate feedback message is larger than of KOR. As a consequence, elaborate feedback might interrupt reading more than KOR, which impedes learning from the extra information in the feedback message and from the text. Another explanation for the equal effectiveness may come from a phenomenon called the redundancy effect (Sweller et al., 1998). If the feedback message presents information that is closely similar to the information in the text, in particular for better skilled readers, this information may be redundant, creating an unnecessary load on the limited working memory capacity of the reader. At the same time, for less skilled readers this information could be a valuable help to integrate the information from the text into a coherent mental model. However, in the present meta-analysis we were not able to take into account differences in students' reading levels as these were often not reported.

The Means of Providing Feedback

The present meta-analysis shows that computer-delivered feedback has a positive effect on learning from text, but that non-computer-delivered feedback has not. Computer-delivered feedback automatically appears when a reader has completed a question or task whereas it takes more time and effort to process a non-computer-delivered feedback message by, for example, retrieving papers from a separate folder, scratching answer forms, using latent image pens or removing flaps that cover the feedback. The difference between these two means of providing feedback seemed especially prominent for feedback presented during reading. These findings are in line with our hypothesis that the time and effort needed to uncover the non-computer-delivered feedback before it can be processed, places a higher demand on working memory capacity (split-attention effect; Sweller, 1994). This demand on working memory seems especially detrimental for learning when feedback is provided during reading, because this form of feedback appeared to already place a burden on working memory.

Limitations and Future Research

In the present meta-analysis we focused on the effects of feedback on learning from text in conventional readers. Nevertheless, this is still a heterogeneous group containing elementary school children, secondary school children and students, all with different levels of reading skills and meta-cognitive skills and reading texts at different levels of complexity. Unfortunately, the fact that a large majority of studies were conducted with college students and university students, the low number of studies with elementary school children and the large overlap between age groups of participants and the timing of feedback, made it impossible to draw strong conclusions about the effects of feedback for different age groups. Nevertheless, the difference in effects of feedback on learning from text between secondary school students and university school students suggest a developmental aspect in the processing of and profiting from feedback. Secondary school children profited less from feedback than university students. Based on the model that the relation between reading achievement and meta-cognitive skills are bi-directional (Edossa et al., 2019) it is plausible that younger readers (i.e., secondary school students) have less well developed meta-cognitive skills, thus responding differently on feedback compared to more proficient readers (i.e., university students). Alternatively, the difference in the effects of feedback on learning from text between secondary school students and university students may arise from differences in students conceptions of feedback. Peterson and Irving (2008) found in their study on students conceptions of assessment and feedback that most secondary school students report that they want feedback that helps them improving learning, but at the same time that many also admit to ignore or forget the given feedback, because they are mainly focused on the summative assessment of their performance (i.e., their grade). As a consequence, they don’t invest to use the feedback to actively improve their performance. From a motivational perspective, differences in the effects of feedback on learning from text between secondary school students and university students may also be explained by the intrinsic motivation of students to perform well in the reading tasks during the feedback interventions. Wigfield et al. (2016) argued that a decrease in reading motivation in secondary school children could partly be explained by a lack of students' believe that what they are learning is relevant. In studies with university students, one could expect students to be much more aware of the reasons why the learning material they are reading is relevant than for secondary school children. This could have consequences for both students' conceptions of feedback and the performance of the students on the reading tests.

Additionally, the groups of elementary school children and secondary school children were probably much more heterogeneous regarding their reading levels than university students. Unfortunately, we were not able to investigate possible differences in the effects of feedback for high or low performing readers. Because low performing or beginning readers need to spend more time and effort to decode words and sentences, less working memory capacity is left to build a mental model of a text (Cain, 2010). As a consequence, these types of readers may also have less working memory capacity left to process questions and the subsequent feedback. This may have implications for the way feedback should be designed for these groups of readers. For example, low performing readers may need other or extra information in feedback messages than high performing readers (i.e., redundancy effect; Sweller et al., 1998). Future research investigating the effects of feedback on learning from text separately for readers of different ages and low and high performing readers could help to gain insight in this matter.

In the present meta-analysis we categorised feedback as KOR, KCR or elaborated feedback (EF). However, as described in the models of Kulhavy and Stock (1989) and Hattie and Timperly (2007), the information in these elaborated feedback messages could greatly vary. To develop a more thorough understanding of what kind of elaborated feedback messages may be most effective in enhancing learning from texts, future research could focus on differences in the effects of different types of elaborated feedback messages (i.e., containing only instructional information (i.e., a repetition of information that is already given in the text) or both instructional and extra-instructional information (i.e., new information or explanations in addition to those already provided in the text); Kulhavy & Stock, 1989; or process-level feedback compared to self-regulation-level feedback; Hattie & Timperley, 2007). According to Kluger and DeNisi (1996) different types of feedback messages may elicit different strategies or learning processes by the learner to reduce the gap between current performance (i.e., in the case of learning from text, the current understanding or mental model of the text) and the goal of a task (i.e., in the case of learning from text, a complete and coherent mental model of the text). The deployment of these strategies may influence the effectiveness of the feedback on learning from text.

Alternatively, in future research the effects of different types of feedback on different levels of information processing could be tested. Information about the level of information processing at which the questions in the direct and delayed post-tests were targeted was hardly reported, which made it impossible to test differences in the effects of feedback on different levels of learning. Learning from or the understanding of a text can be measured on different levels, with an increase in difficulty ranging from questions about facts or sentence-based inferences (i.e., a text-based model or propositional model of the text) to relations between information in sentences among the text and between information in the text and background knowledge (i.e., a situation-model of the text; see Kintsch, 1988). In line with the idea that elaborate feedback would be especially effective to support higher-order learning or deep processing of information, contrary to KOR or KCR, types of feedback that would be more suitable to support knowledge on a surface level (Hattie & Timperley; 2007; van der Kleij et al., 2012), it could be tested in future studies if KOR and KCR would be more effective in supporting learning from text on the level of a superficial, text-based model and if EF would be more effective to promote deep processing of the information in the text.

In the present meta-analysis 74 out of 104 contrasts included interventions of a single session and another 11 contrasts included intervention of at maximum five sessions. In other words, a large majority of the studies was focused on how to provide support 'on the job', i.e., while reading text, to enhance learning from text compared to testing the transferability of strategies targeted by the feedback. In line with this, the majority of the post-test measures used in the primary studies tested the understanding of the content of the texts that were read during the interventions. Hattie and Timperley (2007) argued that feedback on a processing level could help learners to develop effective error-detection skills, information search skills and the use of task strategies, which they can use in new situations, where feedback is not provided by an external agent (e.g., by a computer, teacher or peer), to enhance learning. These metacognitive processes are essential for developing comprehension monitoring skills, that should be used during reading to make meaning from a text (Baker & Brown, 1984).

Finally, in the present meta-analysis we discussed the results from a cognitive load perspective. However, the question of how to determine cognitive load is difficult because of its multidimensional character and the complex interrelationships between performance, cognitive load, and mental effort (see Sweller et al., 1998). In the current meta-analysis it was not possible to test the interaction between different sources of cognitive load (for example the complexity of the information in both the text and feedback messages, modality of presenting feedback, the use of effortful learning processes compared to more automatic learning processes), due to the fact that information with regard to these resources was not reported in the original papers.

Conclusion

The present meta-analysis, including 104 contrasts of reading texts with and without receiving feedback, adds to the field by its narrower scope by specifically testing effects of feedback on learning from texts compared to learning in general in previous meta-analyses (e.g., Hattie, 2012; Shute, 2008; van der Kleij et al., 2015). Also, we only included studies in which there was a direct comparison between a reading with versus a reading without feedback condition. The results of our meta-analysis show that providing feedback during or directly after reading has a positive effect on learning from text. Promoting learning from text appears to be most effective when feedback is presented after reading a text and at least contains the correct answer or is elaborate. Feedback during reading is less effective, probably because it hinders the natural reading process, thereby placing too heavy demands on working memory (i.e., split-attention effect). Additionally, computer-delivered feedback is more beneficial for learning from text than non-computer-delivered feedback. When developing or choosing (educational technologies for) instructional strategies to support learning from text, one should keep in mind that it seems best to minimally interrupt the reading process (i.e., placing minimal load on the limited working memory capacity of the reader), and to help the reader evaluate and, if necessary, revise the mental model of a text with the help of questions or tasks and subsequent elaborate computer-delivered feedback directly after reading.

Table 1

Effects of Feedback During Reading and Directly After Reading on Learning From Text

Moderator variable	Subgroup of studies	k	Average effect size (g+)	SE	95% CI	Heterogeneity statistics
Timing of feedback	After reading	31	0.46*	0.09	[0.28, 0.64]	130.58, $p < .001$
	During reading	69	0.23*	0.06	[0.11, 0.34]	167.73, $p < .001$

Note: $Q_{between}$ (1) = 4.32, $p = .04$; * $p < .001$

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Table 2

Effects of Different Types of Feedback on Learning From Text, Separated for Timing of Feedback

Timing of feedback	Type of feedback	k	Average effect size (g+)	SE	95% CI	p	Heterogeneity statistics (Q_{within})
After reading	KOR	12	0.14	0.18	[-0.21, 0.48]	.45	6.65, p = .65
	KCR	13	0.61	0.18	[0.27, 0.96]	<.001	65.92, p < .001
	Elaborate	6	0.92	0.25	[0.42, 1.42]	<.001	33.61, p <.001
During reading	KOR	11	0.39	0.13	[0.14, 0.64]	< .01	29.67, p = .001
	KOR + KCR	4	0.22	0.21	[-0.20, 0.64]	.31	1.12, p = .77
	KCR	30	0.14	0.08	[-0.02, 0.30]	.08	66.74, p < .001
	Elaborate	24	0.25	0.09	[0.08, 0.42]	< .01	59.32, p < .001

Note: KOR = knowledge-of-response feedback, KCR = knowledge-of-correct-response feedback, EF = elaborate feedback; Moderator statistics for feedback type after reading: $Q(2) = 7.38$, $p = .03$; Moderator statistics for feedback type during reading: $Q(3) = 2.86$, $p = .41$

Table 3

Effects of the Means of Providing Feedback on Learning From Text, Separated for the Timing of Feedback

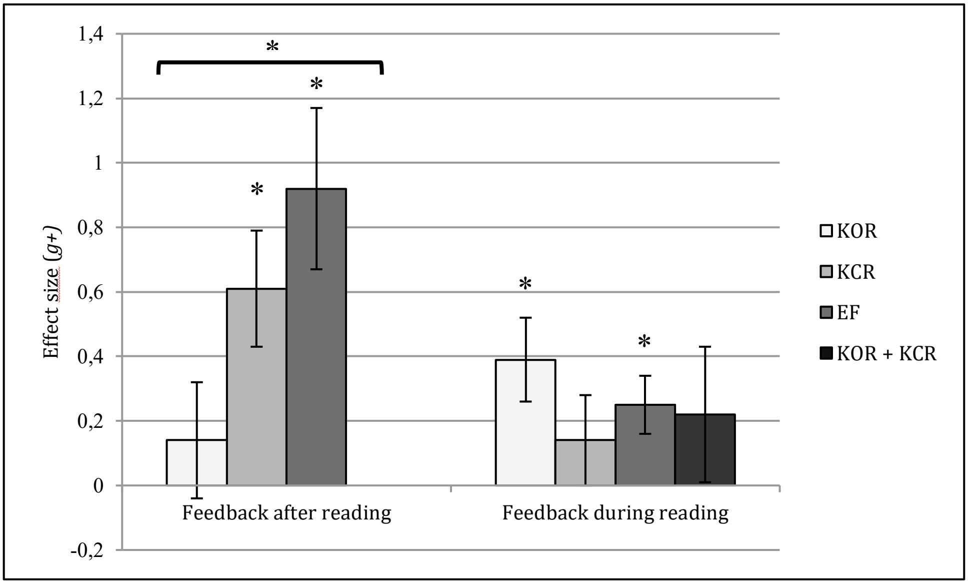
Timing of feedback	Means of providing feedback	k	Average effect size ($g+$)	SE	95% CI	p	Heterogeneity statistics (Q_{within})
After reading	Non-computer-delivered	8	0.19	0.24	[-0.27, 0.65]	.42	5.71, p = .57
	Computer-delivered	23	0.59	0.14	[0.32, 0.85]	< .001	121.71, p < .001
During reading	Non-computer-delivered	28	0.10	0.08	[-0.07, 0.26]	.24	61.98, p < .001
	Computer-delivered	41	0.30	0.07	[0.18, 0.43]	<.001	98.79, p < .001

Note: Moderator statistics for the means of providing feedback after reading: $Q(1) = 2.15$, $p = .14$; Moderator statistics for the means of providing feedback during reading: $Q(1) = 3.78$, $p = .05$

4

Figure 1

Effects of Different Types of Feedback on Learning From Text, Separated for Feedback Timing.



Note: KOR = knowledge-of-response feedback; KCR = knowledge-of-correct-response feedback; EF = elaborate feedback. If feedback was provided after reading, EF was more effective than KOR or KCR to support learning from text. If feedback was provided during reading, no differences were found between the effects of different types of feedback on learning from text. Error bars represent the 95% confidence intervals of the effect sizes. **p* , .05. ** *p* < .01. ****p* < .001.

Appendix A

Combinations of Terms Used for Literacy Search

- book* AND feedback OR book* AND agent OR book* OR book* AND cai OR book* AND tutor OR book* AND feedback AND agent OR book* AND feedback AND avatar OR book* AND feedback AND cai OR book* AND feedback AND model* OR book* AND feedback AND scaffold* OR book* AND feedback AND tutor* OR book* AND interactive AND agent OR book* AND interactive AND avatar OR book* AND interactive AND cai OR book* AND interactive AND model* OR book* AND interactive AND scaffold* OR book* AND interactive AND tutor*
- e-book AND agent OR e-book AND avatar OR e-book AND cai OR e-book AND feedback OR e-book AND interactive OR e-book AND model* OR e-book AND scaffold* OR e-book AND tutor*
- electronic book AND agent OR electronic book AND avatar OR electronic book AND cai OR electronic book AND feedback OR electronic book AND interactive OR electronic book AND model* OR electronic book AND scaffold* OR electronic book AND tutor*
- literacy AND agent OR literacy AND avatar OR literacy AND cai OR literacy AND feedback OR literacy AND interactive OR literacy AND model* OR literacy AND scaffold* OR literacy AND tutor*
- literacy AND books AND agent OR literacy AND books AND avatar OR literacy AND books AND cai OR literacy AND books AND feedback OR literacy AND books AND interactive OR literacy AND books AND model* OR literacy AND books AND scaffold* OR literacy AND books AND tutor*
- literacy AND feedback AND agent OR literacy AND feedback AND avatar OR literacy AND feedback AND cai OR literacy AND feedback AND model* OR literacy AND feedback AND scaffold* OR literacy AND feedback AND tutor*
- literacy AND interactive AND agent OR literacy AND interactive AND avatar OR literacy AND interactive AND cai OR literacy AND interactive AND model* OR literacy AND interactive AND scaffold* OR literacy AND interactive AND tutor*
- literacy AND storybooks AND agent OR literacy AND storybooks AND avatar OR literacy AND storybooks AND cai OR literacy AND storybooks AND model* OR literacy AND storybooks AND scaffold* OR literacy AND storybooks AND tutor*
- reading AND books AND agent OR literacy AND reading AND avatar OR reading AND books AND cai OR reading AND books AND feedback OR reading AND books AND interactive OR reading AND books AND model* OR reading AND books AND scaffold* OR reading AND books AND tutor*

- reading AND feedback AND agent OR reading AND feedback AND avatar OR reading AND feedback AND cai OR reading AND feedback AND model* OR reading AND feedback AND scaffold* OR reading AND feedback AND tutor*
- reading AND interactive AND agent OR reading AND interactive AND avatar OR reading AND interactive AND cai OR reading AND interactive AND model* OR reading AND interactive AND scaffold* OR reading AND interactive AND tutor*
- reading AND storybooks AND agent OR reading AND storybooks AND avatar OR literacy AND storybooks AND cai OR reading AND storybooks AND model* OR reading AND storybooks AND scaffold* OR reading AND storybooks AND tutor* OR storybooks AND cai

Appendix B

References of Searched Handbooks

Barr, R., Kamil, M. L., Mosenthal, P., & Pearson, P. D. (Eds.). (1991). *Handbook of reading: Volume II.* Lawrence Erlbaum Associates.

Bus, A. G. & Neuman, S. B. (Eds.). (2008). *Multimedia and literacy development: Improving achievement for young learners.* Routledge.

Dickinson, D. K. & Neuman, S. B. (Eds.). (2006). *Handbook of early literacy research: Volume II.* The Guilford Press.

Flippo, R. F. & Caverly, D. C. (2000). *Handbook of college reading and study strategy research* (2nd edition). Lawrence Erlbaum Associates.

Hall, N. , Larson, J., & Marsh, J. (Eds.). (2003). *Handbook of early childhood literacy.* SAGE Publications.

Israel, S. E. & Duffy, G. G. (Eds.). (2009). *Handbook of research on reading comprehension.* Taylor & Francis.

Kamil, M. L., Mosenthal, P. B., Pearson, P. D. & Barr, R. (Eds.). (2000). *Handbook of reading: Volume III.* Lawrence Erlbaum Associates.

Kinzer, C. & Verhoeven, L. T. (Eds.). (2007). *Interactive literacy education: Facilitating literacy environments through technology.* Lawrence Erlbaum Associates.

Mayer, R. E. (Ed.). (2005). *The Cambridge handbook of multimedia learning.* Cambridge University Press.

McKenna, M. C., Labbo, L. D., Kieffer, R. D. & Reinking, D. (Eds.). (2006). *International handbook of literacy and technology: Volume II*. Lawrence Erlbaum Associates.

McNamara, D.S. (Ed.) (2007). *Reading Comprehension Strategies: Theories, Interventions, and Technologies.* Lawrence Erlbaum Associates.

Morrow, L. M., Rueda, R., & Lapp, D. (2009). *Handbook of research in literacy and diversity.* The Guilford Press.

Neuman, S. B. & Dickinson, D. K. (Eds.). (2001). *Handbook of early literacy research: Volume I.* The Guilford Press.

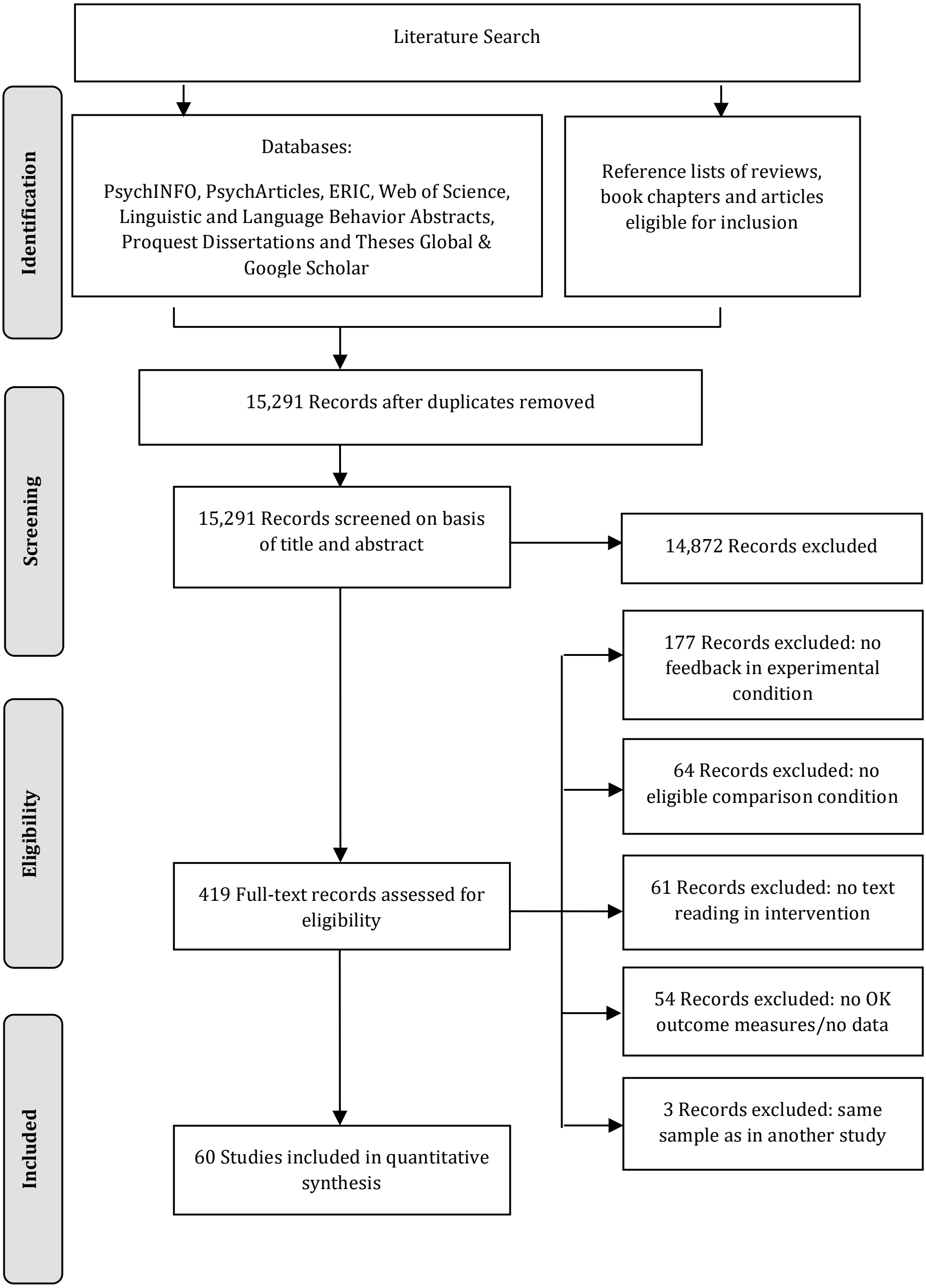
O'Connor, R. E. & Vadasy, P. F. (Eds.). (2011). *Handbook of reading interventions.* The Guilford Press.

Olson, D. R. & Torrance, N. (Eds.). (2009). *The Cambridge handbook of literacy.* Cambridge University Press.

Pearson, P. D., Barr, R., Kamil, M. L., & Mosenthal, P. (Eds.). (2002). *Handbook of reading research: Volume I.* Lawrence Erlbaum Associates.

Appendix C

PRISMA Flow Diagram



Appendix D

References of Studies Included in the Present Meta-Analysis

Adams, R. H., & Strickland, J. (2012). The effects of computer-assisted feedback strategies in technology education: A comparison of learning outcomes. *Journal of Educational Technology Systems, 40*, 211-223. doi:10.2190%2FET.40.2.i

Anderson, R. C., Kulhavy, R. W., & Andre, T. (1971). Feedback procedures in programmed instruction. *Journal of Educational Psychology*, *62*, 148-156. doi:10.1037/h0030766

Anderson, R. C., Kulhavy, R. W., & Andre, T. (1972). Conditions under which feedback facilitates learning from programmed lessons. *Journal of Educational Psychology, 63*, 186-188. doi:10.1037/h0032653

Azevedo, R., Landis, R. S., Feyi-Behnagh, Duffy, M., Trevors, G., Harley, J. M., Bouchet, F., Burlison, J., Taub, M., Pacampara, N., Yeasin, M., Rahman, A. K. M. M., Tanveer, M. I., & Hossain, G. (2012). The effectiveness of pedagogical agents' prompting and feedback in facilitating co-adapted learning with MetaTutor. In: S. A. Cerri, W. J. Clancey, G. Papadourakis, K. Panourgia (Eds). *Intelligent Tutoring Systems. ITS 2012. Lecture Notes in Computer Science, Vol. 7315* (pp. 212-221). Springer. doi:10.1007/978-3-642-30950-2_27

Butler, A. C., Godbole, N., & Marsh, E. J. (2013). Explanation feedback is better than correct answer feedback for promoting transfer of learning. *Journal of Educational Psychology, 105*, 290-298. doi:10.1037/a0031026

Chanond, K. (1988). *The effects of feedback, correctness of response, and response confidence on learner's retention in computer-assisted instruction* (Publication No. 8816422) [Doctoral dissertation, The University of Texas at Austin]. Proquest Dissertations and Theses Global.

Chen, N. S., Teng, D. C. E., & Lee, C. H. (2011). Augmenting paper-based reading activity with direct access to digital materials and scaffolded questioning. *Computers & Education, 57*, 1705-1715. doi:10.1016/j.compedu.2011.03.013

Clariana, R. B., & Koul, R. (2006). The effects of different forms of feedback on fuzzy and verbatim memory of science principles. *British Journal of Educational Psychology, 76*, 259-270. doi:10.1348/000709905X39134

Clariana, R.B., Ross, S.M. & Morrison, G.R. (1992, February 5-9). *The effects of different feedback strategies using computer-administered multiple-choice questions as instruction* [Paper presentation]. The 14th Convention of the Association for Educational Communications and Technology and Sponsored by the Research and Theory Division. Washington D. C., USA.

Clark, K., & Dwyer, F. (1998). Effect of different types of computer-assisted feedback strategies on achievement and response confidence. *International Journal of Instructional Media, 25*(1), 55-63.

Elliot, B. A. (1986). *An investigation of the effects of computer feedback and interspersed questions on the text comprehension of poor readers (computer-assisted instruction)* (Publication No. 303529305) [Doctoral dissertation, Temple University]. ProQuest Dissertations & Theses Global.

Farragher, P. (1980). *Learning environmental science from text aided by a diagnostic and prescriptive instructional strategy* (Publication No. 8024445) [Doctoral dissertation, The Pennsylvania State University). ProQuest Dissertations & Theses Global.

Farragher, P., & Yore, L. D. (1997). The effects of embedded monitoring and regulating devices on the achievement of high school students learning science from text. *School Science and Mathematics, 97*, 87-95. doi:10.1111/j.1949-8594.1997.tb17348.x

Fazio, L. K., Huelser, B. J., Johnson, A., & Marsh, E. J. (2010). Receiving right/wrong feedback: Consequences for learning. *Memory, 18*, 335-350. doi:10.1080/09658211003652491

Feldhusen, J. F., & Birt, A. (1962). A study of nine methods of presentation of programmed learning material. *The Journal of Educational Research, 55*, 461-466. d doi:10.1080/00220671.1962.10882854

Feng, B., & Reigeluth, C. M. (1983). *The effect of three different kinds of feedback: Hint, correct answer, and right/wrong* (IDD&E Working Paper No. 11). Syracuse University, New York School of Education.

Fernald, P. S., & Jordan, E. A. (1991). Programmed instruction versus standard text in introductory psychology. *Teaching of Psychology, 18*, 205-211. doi:10.1207%2Fs15328023top1804_1

Franzke, M., Kintsch, E., Caccamise, D., Johnson, N., & Dooley, S. (2005). Summary Street®: Computer support for comprehension and writing. *Journal of Educational Computing Research, 33*, 53-80. doi:10.2190/DH8F-QJWM-J457-FQVB

Goldbeck, R. A., & Campbell, V. N. (1962). The effects of response mode and response difficulty on programed learning. *Journal of Educational Psychology, 53*, 110-118. doi:10.1037/h0044479

Golke, S., Dörfler, T., & Artelt, C. (2009). Effects of accuracy feedback during a text comprehension test. *Educational & Child Psychology, 26*(3), 30-39. doi:10.1007/s10763-014-9575-4

Golke, S., Dörfler, T., & Artelt, C. (2015). The impact of elaborated feedback on text comprehension within a computer-based assessment. *Learning and Instruction, 39*, 123-136. doi:10.1016/j.learninstruc.2015.05.009

Hoffmann, B. S. (1974). *An examination of knowledge of results and step size in programmed instruction at high and low cognitive levels of objectives* (Publication No. 7501707) [Doctoral dissertation, Indiana University]. ProQuest Dissertations & Theses Global.

Hogg, P., Boyle, T., & Lawson, R. (1999). Comparative evaluation of a CORE based learning environment for nuclear medicine. *Journal of Educational Multimedia and Hypermedia, 8*, 457-473. doi:10.1111/j.1470-3327.2005.00614.x

Huang, J. C.-Y. (1995, February 8-10). *Effects of types of feedback on achievement and attitudes during computer-based cooperative condition* [Paper presentation]. Annual National Convention of the Association for Educational Communications and Technology, USA. Anaheim, CA, United States.

Hyman, C., & Tobias, S. (1981, October 21-23). *Feedback and prior achievement* [Paper presentation]. Annual Meeting of the North-eastern Educational Research Association, Ellenville, NY, United States.

Jacobs, P. I., & Kulkarni, S. (1963). A test of some assumptions underlying programed instruction. *Psychological Reports, 18,* 103-110. doi:10.1002/j.2333-8504.1963.tb00495.x

Kang, S. H. K., McDermott, K. B. & Roediger III, H. L., (2007) Test format and corrective feedback modify the effect of testing on long-term retention. *European Journal of Cognitive Psychology, 19*, 528-558. doi:10.1080/09541440601056620

Kauffman, D. F. (2004). Self-regulated learning in web-based environments: Instructional tools designed to facilitate cognitive strategy use, metacognitive processing, and motivational beliefs. *Journal of Educational Computing Research, 30*, 139-161. doi:10.2190%2FAX2D-Y9VM-V7PX-0TAD

Kealy, W. A. & Ritzhaupt, A. D. (2010). Assessment certitude as a feedback strategy for learners' constructed responses. *Journal of Educational Computing Research*, *43*, 25-45. doi:10.2190%2FEC.43.1.c

Krumboltz, J. D., & Weisman, R. G. (1962). The effect of intermittent confirmation in programed instruction. *Journal of Educational Psychology, 53*, 250-253. doi:10.1037/h0040448

Kulhavy, R. W., Yekovich, F. R., & Dyer, J. W. (1976). Feedback and response confidence. *Journal of Educational Psychology, 68*, 522-528. doi:10.1037/0022-0663.68.5.522

Kulhavy, R. W., Yekovich, F. R., & Dyer, J. W. (1979). Feedback and content review in programmed instruction. *Contemporary Educational Psychology, 4*, 91-98. doi:10.1016/0361-476X(79)90062-6

Lasoff, E. M. (1981). *The effects of feedback in both computer-assisted instruction and programmed instruction on achievement and attitude* (Publication No. 8121115) [Doctoral dissertation, University of Miami]. ProQuest Dissertations and Theses Global.

Lee, H. W., Lim, K. Y., & Grabowski, B. L. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development, 58*, 629-648. doi:10.1007/s11423-010-9153-6

Lhyle, K. G., & Kulhavy, R. W. (1987). Feedback processing and error correction. *Journal of Educational Psychology, 79*, 320-322. doi:10.1037/0022-0663.79.3.320

Lin, H. (2006). *The effect of questions and feedback used to complement static and animated visualization on tests measuring different educational objectives* (Publication No. 3318901) [Doctoral dissertation, The Pennsylvania State University]. ProQuest Dissertations & Theses Global.

Llorens, A. C., Cerdán, R., & Vidal-Abarca, E. (2014). Adaptive formative feedback to improve strategic search decisions in task-oriented reading. *Journal of Computer Assisted Learning, 30*, 233-251. doi:10.1111/jcal.12050

Llorens, A. C., Vidal-Abarca, E., & Cerdán, R. (2016). Formative feedback to transfer self-regulation of task-oriented reading strategies. *Journal of Computer Assisted Learning, 32*, 314-331. doi:10.1111/jcal.12134

Lublin, S. C. (1965). Reinforcement schedules, scholastic aptitude, autonomy need, and achievement in a programed course. *Journal of Educational Psychology, 56*, 295-302. doi:10.1037/h0022790

Martin, F., Klein, J. D., & Sullivan, H. (2007). The impact of instructional elements in computer-based instruction. *British Journal of Educational Technology, 38*, 623-636. doi:10.1111/j.1467-8535.2006.00670.x

Martin S. A., Azevedo R., Taub M., Mudrick N. V., Millar G. C., Grafsgaard J. F. (2016) Are there benefits of using multiple pedagogical agents to support and foster self-regulated learning in an intelligent tutoring system? In: A. Micarelli, J. Stamper, K. Panourgia (Eds.) *Intelligent tutoring systems: Lecture notes in computer science.* (Vol. 9684, pp. 273-279). doi:10.1007/978-3-319-39583-8_29

Merrill, D. M. (1965). Correction and review on successive parts in learning a hierarchical task. *Journal of Educational Psychology, 56*, 225-234. doi:10.1037/h0022471

Moore, J. W., & Smith, W. I. (1964). Role of knowledge of results in programed instruction. *Psychological Reports, 14*, 407-423. doi:10.2466%2Fpr0.1964.14.2.407

Morrison, G. R., Ross, S. M., Gopalakrishnan, M., & Casey, J. (1995). The effects of feedback and incentives on achievement in computer-based instruction. *Contemporary Educational Psychology, 20*, 32-50. doi:10.1006/ceps.1995.1002

Nelson, W. A. (1992, April 20-24). *Adaptive hypermedia instructional systems: Possibilities for learner modelling* [Paper presentation]. Annual Meeting of the American Educational Research Association. San Fransisco, CA, United States.

Nishikawa, S. (1988, January 14-19). *Effects of feedback strategies in computer assisted instruction and the influence of locus of control on the performance of junior high students* [Paper Presentation]. Annual Convention of the Association for Educational Communications and Technology. New Orleans, LA, United States.

Olson, G. H. (1971). *A multivariate examination of the effects of behavioral objectives, knowledge of results, and the assignment of grades on the facilitation of classroom learning* (Publication No. 7213552) [Doctoral dissertation, The Florida State University]. ProQuest Dissertations & Theses Global.

Peverly, S. T., & Wood, R. (2001). The effects of adjunct questions and feedback on improving the reading comprehension skills of learning-disabled adolescents. *Contemporary Educational Psychology, 26,* 25-43. doi:10.1006/ceps.1999.1025

Pridemore, D. R., & Klein, J. D. (1995). Control of practice and level of feedback in computer-based instruction. *Contemporary Educational Psychology, 20*, 444-450. doi:10.1006/ceps.1995.1030

Razagifard, P., Ghabelnezam, A., & Fard, V. F. (2011). The effect of computer-mediated feedback on second language reading comprehension. *International Journal on New Trends in Education and Their Implications, 2*(1), 90-98.

Ripple, R. E. (1963). Comparison of the effectiveness of a programed text with three other methods of presentation. *Psychological Reports, 12*, 227-237. doi:10.2466%2Fpr0.1963.12.1.227

Rothkopf, E. Z. (1966). Learning from written instructive materials: An exploration of the control of inspection behavior by test-like events. *American Educational Research Journal, 3*, 241-249. doi:10.3102%2F00028312003004241

Saunders, P. H. (1998). *The effectiveness of paraphrasing and feedback in computer-based instruction* (Publication No. 9905104) [Doctoral dissertation, The University of Memphis]. ProQuest Dissertations & Theses Global.

Sung, Y. T., Chang, K. E., & Huang, J. S. (2008). Improving children's reading comprehension and use of strategies through computer-based strategy training. *Computers in Human Behavior, 24,* 1552-1571. doi:10.1016/j.chb.2007.05.009

Tobias, S. (1987). Mandatory text review and interaction with student characteristics. *Journal of Educational Psychology, 79,* 154-161. doi:10.1037/0022-0663.79.2.154

Tobias, S. (1988). Teaching strategic text review by computer and interaction with student characteristics. *Computers in Human Behavior, 4*, 299-310. doi:10.1016/0747-5632(88)90002-7

Tobias, S., & Ingber, T. (1976). Achievement-treatment interactions in programmed instruction. *Journal of Educational Psychology, 68,* 43-47. doi:10.1037/0022-0663.68.1.43

Tsao, P. K. (1977). *The effects of error rate, knowledge of correct results and test anxiety in linear program* (Publication No. 7815385) [Doctoral dissertation, The University of Oklahoma]. ProQuest Dissertations & Theses Global.

Valdez, A. J. (2008). *Encouraging mindful feedback processing: Computer-based instruction in descriptive statistics* (Publication No. 3329482) [Doctoral dissertation, The University of New Mexico]. ProQuest Dissertations & Theses Global.

Wentling, T. L. (1973). Mastery versus nonmastery instruction with varying test item feedback treatments. *Journal of Educational Psychology, 65,* 50-58. doi:10.1037/h0034820

Appendix E

Overview of Studies Included in the Meta-Analysis, Including Moderator Variables and Effect Sizes

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Adams & Strickland	2012	J	17	17	Stu.	N	B	4	Inf.	Text only	KCR	After	Computer	MC-questions	0.00
Anderson et al.	1971A Exp. 1	J	21	21	Stu.	Y	B	1	Inf.	Text + pic.	KCR	During	Computer	Open + MC-questions	1.10
Anderson et al.	1971B Exp. 2	J	24	26	Stu.	Y	B	1	Inf.	Text + pic.	KCR	During	Computer	Open + MC-questions	0.60
Anderson et al.	1972	J	24#	24#	Stu.	Y	B	1	Inf.	Text only	KCR	During	Computer	Open + MC-questions	0.41
Azevedo et al.	2012	CP	23#	23#	Stu.	Y	B	1	Inf.	Text + pic.	EF	During	Computer	MC-questions	1.05
Butler & Roediger III	2008	J	26	26	Stu.	Y	W	1	Nar.	Text only	KCR	After	Computer	Open questions	0.52
Butler et al.	2013A	J	20	10*	Stu.	Y	B	1	Inf.	Text only	EF	After	Computer	Open questions	1.22
Butler et al.	2013B	J	20	10*	Stu.	Y	B	1	Inf.	Text only	KCR	After	Computer	Open questions	0.62
Chanond	1988	D	60	60	Stu.	Y	B	1	Inf.	Text + pic.	EF	During	Computer	MC-questions	0.77
														Del.: MC-questions	0.26
Chen et al.	2011A	J	19	19	Stu.	Y	B	1	Inf.	Text + video	KOR	During	Computer	MC-questions	0.05
Chen et al.	2011B	J	20	20	Stu.	Y	B	1	Inf.	Text + video	KOR	During	Computer	MC-questions	0.67
Clariana & Koul	2006	J	17	16	Sec.	Y	B	1	Inf.	Text only	KCR	After	Non-com.	MC-questions	0.19

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Clariana et al.	1992	CP	10	10	Sec.	Y	B	1	Inf.	Text only	KCR	-	Computer	MC-questions	2.40
														Del.: MC-questions	2.30
Clark & Dwyer	1998	J	37	47	Stu.	Y	B	1	Inf.	Text + pic.	EF	After	Computer	MC-questions	0.10
Elliot	1986	D	20	22	Sec.	Y	B	1	Inf.	Text only	EF	During	Computer	MC-questions	0.41
Farragher	1980A	D	30	10*	Stu.	Y	B	1	Inf.	Text only	KOR	During	Non-com.	MC-questions	-0.21
														Del.: MC-questions	-0.32
Farragher	1980B	D	30	10*	Stu.	Y	B	1	Inf.	Text only	EF	During	Non-com.	MC-questions	-0.18
														Del.: MC-questions	-0.24
Farragher	1980C	D	30	10*	Stu.	Y	B	1	Inf.	Tex only	EF	During	Non-com.	MC-questions	0.42
														Del.: MC-questions	0.28
Farragher & Yore	1997A	J	25	13*	Sec.	Y	B	1	Inf.	Text + pic.	EF	During	Non-com.	MC-questions	0.09
														Del.: MC-questions	-0.07
Farragher & Yore	1997B	J	25	12*	Sec.	Y	B	1	Inf.	Text + pic.	EF	During	Non-com.	MC-questions	0.09
														Del.: MC-questions	0.06
Fazio et al.	2010	J	48	48	Stu.	Y	W	1	Inf.	Text only	KCR	After	Computer	Open questions	1.21
Feldhusen & Birt	1962A	J	30	10*	Stu.	Y	B	1	Inf.	Text only	KCR	During	Computer	Questions (unkn.)	0.35
Feldhusen & Birt	1962B	J	30	10*	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Questions (unkn.)	0.23

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Feldhusen & Birt	1962C	J	30	10*	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Questions (unkn.)	0.34
Feng & Reigeluth	1983	Rep.	12	10	Pr.	N	B	1	Inf.	Text only	EF	During	Non-com.	MC-questions	1.31
Fernald & Jordon	1991A	J	18	18	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	MC-questions	0.11
Fernald & Jordon	1991B	J	18	16	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	MC-questions	0.05
Fernald & Jordon	1991C	J	16	15	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	MC-questions	-0.45
Franzke et al.	2005	J	52	59	Sec.	Y	B	8	Both	Text only	KOR	After	Computer	Questions (unkn.)	0.16
Goldbeck & Campbell	1962	J	16#	16#	Sec.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Questions (unkn.)	-0.27
														Del.: Questions (unkn.)	-0.65
Golke et al.	2009	J	100	98	Sec.	Y	B	1	Both	Text only	KOR	After	Computer	MC-questions	-0.12
Golke et al.	2015A Exp. 1	J	108	28*	Sec.	Y	B	1	Both	Text only	EF	During	Computer	MC-questions	-0.18
														Del.: MC-questions	-0.12
Golke et al.	2015B Exp. 1	J	111	27*	Sec.	Y	B	1	Both	Text only	KOR	During	Computer	MC-questions	-0.11
														Del.: MC-questions	-0.01

4

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Golke et al.	2015C Exp. 1	J	113	27*	Sec.	Y	B	1	Both	Text only	EF	During	Computer	MC-questions Del.: MC-questions	-0.22 -0.09
Golke et al.	2015D Exp. 1	J	120	27*	Sec.	Y	B	1	Both	Text only	EF	During	Computer	MC-questions Del.: MC-questions	0.11 -0.02
Golke et al.	2015E Exp. 2	J	61	30*	Sec.	Y	B	1	Both	Text only	EF	During	Computer	MC-questions	0.37
Golke et al.	2015F Exp. 2	J	63	30*	Sec.	Y	B	1	Both	Tet only	EF	During	Computer	MC-questions	0.05
Hoffmann	1974	D	16#	16#	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open questions	-0.10
Hogg et al.	1999	J	8	10	Stu.	N	B	-	Inf.	Text + video	KOR	After	Computer	Open + MC-questions	0.81
Huang	1995A	CP	40	20*	Stu.	Y	B	2	Inf.	-	KCR	During	Computer	Del.: MC-questions	1.93
Huang	1995B	CP	40	20*	Stu.	Y	B	2	Inf.	-	EF	During	Computer	Del.: MC-questions	2.41[w]
Hyman & Tobias	1981	CP	46	42	Pr.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open questions	-0.19
Jacobs & Kulkarni	1966A	J	15	12	Sec.	Y	B	-	Inf.	Text + pic.	KCR	During	Non-com.	Open + MC-questions	-0.91
Jacobs & Kulkarni	1966B	J	19	9	Sec.	Y	B	-	Inf.	Text + pic.	KCR	During	Non-com.	Open + MC-questions	-0.39
Kang et al.	2007A	J	48	24*	Stu.	Y	W	1	Inf.	Text only	KCR	After	Computer	Open + MC-questions	0.85

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Kang et al.	2007B	J	48	24*	Stu.	Y	W	1	Inf.	Text only	KCR	After	Computer	Open + MC-questions	1.23
Kauffman	2004A	J	15#	15#	Stu.	Y	B	1	Inf.	Text only	KOR	After	Computer	Open + MC-questions	0.41
Kauffman	2004B	J	15#	15#	Stu.	Y	B	1	Inf.	Text only	KOR	After	Computer	Open + MC-questions	0.53
Kauffman	2004C	J	15#	15#	Stu.	Y	B	1	Inf.	Text only	KOR	After	Computer	Open + MC-questions	0.05
Kauffman	2004D	J	15#	15#	Stu.	Y	B	1	Inf.	Text only	KOR	After	Computer	Open + MC-questions	-0.03
Kealy & Ritzhaupt	2010	J	21	19	Stu.	Y	B	1	Nar.	Text only	KCR	After	Computer	Open questions + recall	0.32
Krumboltz & Weisman	1962	J	20	25	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open questions	0.18
Kulhavy et al.	1976	J	30	30	Stu.	Y	B	1	Inf.	Text + pic.	KOR	During	Non-com.	MC-questions	0.51
														Del.: MC-questions	0.55
Kulhavy et al.	1979	J	60	60	Stu.	Y	B	1	Inf.	Text + pic.	KOR	During	Non-com.	MC-questions	0.70
Lasoff	1981A	D	12	12	Stu.	Y	B	5	Inf.	Text only	EF	During	Computer	MC-questions	-0.32
Lasoff	1981B	D	10	10	Stu.	Y	B	5	Inf.	Text only	EF	During	Non-com.	MC-questions	0.00
Lee et al.	2010	J	74#	74#	Stu.	Y	B	1	Inf.	Text + pic.	KOR	During	Computer	MC-questions	0.54

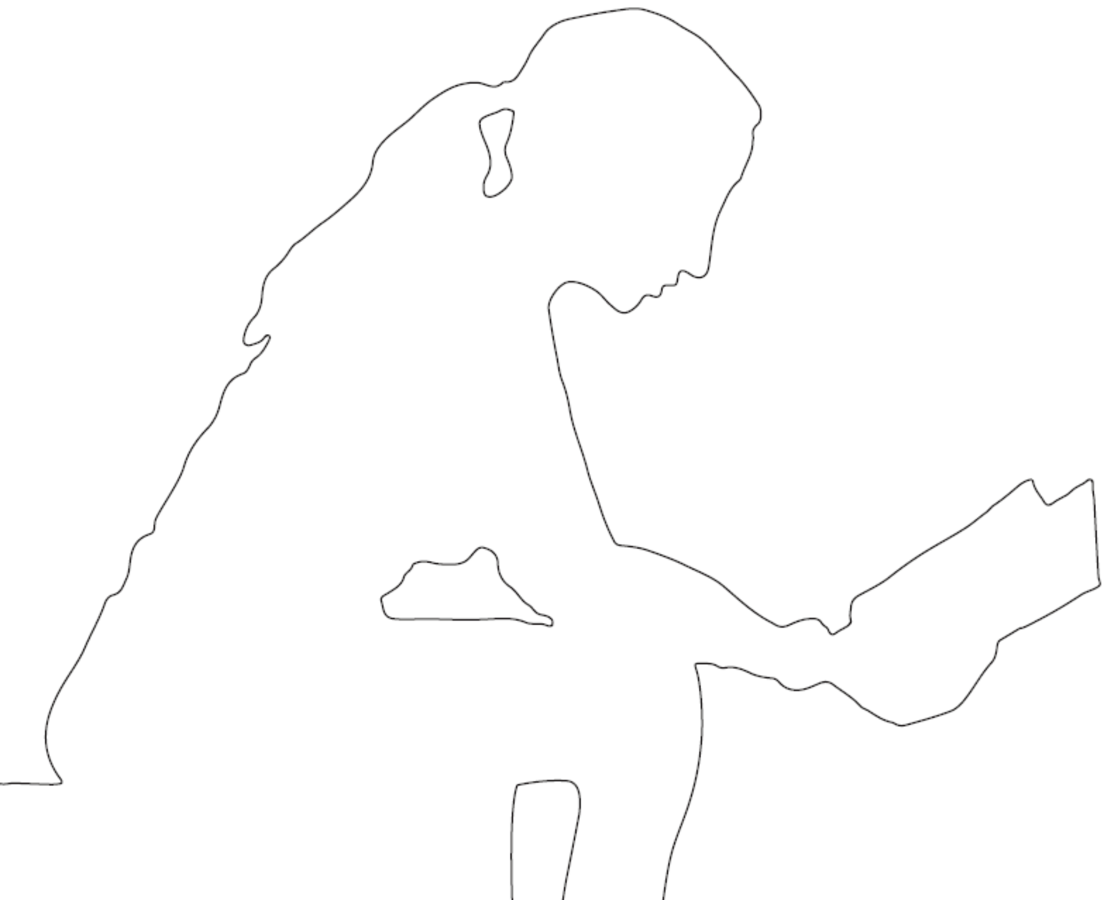
Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Lhyle & Kulhavy	1987	J	20	20	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	MC-questions	1.26
Lin	2006	D	194	194	Stu.	Y	B	1	Inf.	Text + video	EF	During	Computer	Open + MC-questions	0.10
Llorens et al.	2014A	J	30	14*	Sec	Y	B	1	Inf.	Text + pic.	EF	During	Computer	MC-questions	0.67
Llorens et al.	2014B	J	34	14*	Sec.	Y	B	1	Inf.	Text + pic.	KCR	During	Computer	MC-questions	0.35
Llorens et al.	2016A Exp. 1	J	51	25*	Sec.	Y	B	1	Inf.	Text only	EF	During	Computer	MC-questions	0.10
Llorens et al.	2016B Exp. 1	J	41	25*	Sec.	Y	B	1	Inf.	Text only	EF	During	Computer	MC-questions	0.16
Llorens et al.	2016C Exp. 2	J	38	37	Sec.	Y	B	1	Inf.	Text only	EF	During	Computer	MC-questions	0.05
Lublin	1965	J	55#	55#	Stu.	Y	B	12	Inf.	Text + pic.	KCR	During	Non-com.	Open questions	-0.55
Martin et al.	2007	J	43#	43#	Stu.	Y	B	1	Inf.	Text + pic.	KOR	During	Computer	MC-questions	1.11
Martin et al.	2016	CP	82#	83#	Stu.	Y	B	2	Inf.	Text + pic.	EF	During	Computer	MC-questions	0.41
Merrill	1965	J	14	12	Stu.	Y	B	-	Inf.	Text only	EF	During	Computer	MC-questions	2.03
Moore & Smith	1964A	J	22	22	Stu.	Y	B	12	Inf.	Text only	KCR	During	Computer	Open + MC-questions	0.47

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Moore & Smith	1964B	J	22	22	Stu.	Y	B	12	Inf.	Text only	KCR	During	Computer	Open + MC-questions	0.92
Morrison et al.	1995A	J	51	24*	Stu.	Y	B	1	Inf.	Text only	KCR	During	Computer	MC-questions	0.24
Morrison et al.	1995B	J	49	24*	Stu.	Y	B	1	Inf.	Text only	KOR	During	Computer	MC-questions	-0.18
Nelson	1992	CP	12	12	Stu	Y	B	1	Inf.	Text only	KOR	During	Computer	Open questions	0.32
Nishikawa	1988	CP	10	13	Sec.	N	B	1	Inf.	Text + pic.	KCR	During	Computer	Questions (unkn.)	0.08
														Del.: Questions (unkn.)	0.01
Olson	1971A	D	13	12	Stu.	Y	B	4	Inf.	Text + pic.	KOR	After	Non-com.	MC-questions	0.40
														Del.: MC-questions	0.27
Olson	1971B	D	12	13	Stu.	Y	B	4	Inf.	Text + pic.	KOR	After	Non-com.	MC-questions	0.51
														Del.: MC-questions	0.24
Olson	1971C	D	13	13	Stu.	Y	B	4	Inf.	Text + pic.	KOR	After	Non-com.	MC-questions	0.09
														Del.: MC-questions	0.00
Olson	1971D	D	13	12	Stu.	Y	B	4	Inf.	Text + pic.	KOR	After	Non-com.	MC-questions	-0.05
														Del.: MC-questions	-0.13
Peverly & Wood	2001A	J	10	10	Sec.	Y	B	6	Nar.	Text only	KCR	During	Non-com.	Open questions	0.12
Peverly & Wood	2001B	J	10	10	Sec.	Y	B	6	Nar.	Text only	KCR	After	Non-com.	Open questions	0.68
Pridemore & Klein	1995A	J	35#	18#*	Sec.	Y	B	2	Inf.	Text + pic.	EF	During	Computer	Open + MC-questions	0.07

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Pridemore & Klein	1995B	J	35#	17#*	Sec.	Y	B	2	Inf.	Text + pic.	KCR	During	Computer	Open + MC-questions	-0.22
Pridemore & Klein	1995C	J	35#	18#*	Sec.	Y	B	2	Inf.	Text + pic.	EF	During	Computer	Open + MC-questions	0.06
Pridemore & Klein	1995D	J	35#	17#*	Sec.	Y	B	2	Inf.	Text + pic.	KCR	During	Computer	Open + MC-questions	-0.15
Razagifard et al.	2011	J	30	30	Stu.	Y	B	4	-	Text only	KOR + KCR	-	Computer	Questions (unkn.)	0.94
Ripple	1963	J	60	60	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open + MC-questions Del.: Open + MC-questions	0.01 0.21
Rothkopf	1966	J	21	21	Stu.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open questions	0.46
Saunders	1998A	D	17	17	Stu	Y	B	1	Inf.	Text only	KCR	After	Computer	Open + MC-questions	-0.14
Saunders	1998B	D	17	17	Stu	Y	B	1	Inf.	Text only	KCR	After	Computer	Open + MC-questions	-0.44
Sung et al.	2008A	J	31	35	Pr.	N	B	22	Both	Text only	EF	After	Non-com.	MC-questions	0.22
Sung et al.	2008B	J	34	30	Pr.	N	B	22	Both	Text only	EF	After	Non-com.	MC-questions	0.54
Tobias	1987A	J	37	19*	Sec.	Y	B	1	Inf.	Text only	KOR + KCR	During	Computer	Open questions	0.20
Tobias	1987B	J	37	18*	Sec.	Y	B	1	Inf.	Text only	KOR + KCR	During	Computer	Open questions	0.20

Authors	Year	Pub. Type	*N* fb	*N* cont	Age	Randomly assigned	Subject design	Nr. of sessions	Text type	Text design	Feedback Type	Feedback Timing	Means of providing feedback	Outcome measure	Effect size (Hedges'*g*)
Tobias	1988A	J	25	25	Sec.	Y	B	1	Inf.	Text only	KOR + KCR	During	Computer	Open questions	0.21
Tobias	1988B	J	20	23	Sec.	Y	B	1	Inf.	Text only	KOR + KCR	During	Computer	Open questions	0.46
Tobias & Ingber	1976	J	$52^{\#}$	$52^{\#}$	Pr.	Y	B	1	Inf.	Text only	KCR	During	Non-com.	Open questions	0.15
Tsao	1977A	D	20	20	Stu.	Y	B	1	Inf.	-	KCR	During	Non-com.	Open questions	0.19
Tsao	1977B	D	20	20	Stu.	Y	B	1	Inf.	-	KCR	During	Non-com.	Open questions	-0.11
Valdez	2008A	D	$22^{\#}$	$11^{\#*}$	Stu.	Y	B	1	Inf.	Text + pic.	EF	After	Computer	MC-questions	1.94
Valdez	2008B	D	$22^{\#}$	$10^{\#*}$	Stu.	Y	B	1	Inf.	Text + pic.	KCR	After	Computer	MC-questions	2.25
Valdez	2008C	D	$22^{\#}$	$11^{\#*}$	Stu.	Y	B	1	Inf.	Text + pic.	EF	After	Computer	MC-questions	2.41^{w}
Valdez	2008D	D	$22^{\#}$	$10^{\#*}$	Stu.	Y	B	1	Inf.	Text + pic.	KCR	After	Computer	MC-questions	2.40^{w}
Wentling	1973A	J	$39^{\#}$	$19^{\#}$	Sec.	N	B	20	Inf.	Text only	KOR	After	Non-com.	MC-questions	0.17
														Del.: MC-questions	-0.04
Wentling	1973B	J	$39^{\#}$	$20^{\#}$	Sec.	N	B	20	Inf.	Text only	KOR	After	Non-com.	MC-questions	-0.31
														Del.: MC-questions	-0.20

Note: Publication type: CP = conference proceeding, D = dissertation, J = journal article, Rep. = report. Age: Pr. = primary school students, Sec. = secondary school students, *N* fb = number of participants in the feedback condition. *N* cont = number of participants in the control condition. Stu. = university students. Randomly assigned: Y = yes, random assignment of participants to condition on an individual level, N = no random assignment or randomization at classroom/group level. Subject design: B = between-subject design, W = within-subject design. Text type: Inf. = informative text(s), Nar. = narrative text(s), Both = informative and narrative texts. Text design: Text + pic. = text accompanied by pictures, Text + video = text accompanied by animations or video content. FB Type: KOR = knowledge-of-response feedback, KCR = knowledge-of-correct-response feedback, EF = elaborate feedback. Means of providing feedback: non-com. = non-computer-delivered, Computer = computer-delivered. Outcome measure: Del. = delayed post-test, Questions (unkn.) = type of comprehension questions is unknown. # = number of participants estimated based on the total sample size and the number of conditions in a study. * Number of participants in the control group was split among multiple contrasts. ^{w} = winsorized effect size



Chapter 5

Explaining the Effect of Feedback on Reading Comprehension: A Meta-Analysis on the Effects of Feedback on the Use of Reading Strategies and Motivational Aspects

Based on:

Swart, E. K., Nielen, T. M. J., & Sikkema-de Jong, T. M. (under review). Explaining the effect of feedback on reading comprehension: A meta-analysis on the effects of feedback on the use of reading strategies and motivational aspects.

Abstract

Background: Previous meta-analytic research has shown that feedback given when students perform a reading task positively influences learning from text but that the effects are moderated by the timing and the richness of feedback. An unanswered question, however, is whether the positive effects of feedback could be explained by its influence on the capability to use reading strategies or on motivational aspects. In the present meta-analysis we aim to answer this question.

Method: Two meta-analyses were performed on feedback intervention studies that included statistics for both the effect of feedback on the use of reading strategies (k =8) or motivational aspects (k = 10) and the effect of feedback on reading comprehension. In case of a significant effect of feedback on the use of reading strategies or motivational aspects, a meta-regression analysis was performed to test if the magnitude of these effects moderated the effect of feedback on reading comprehension.

Results: Results showed that feedback had a positive and significant impact on the use of reading strategies when reading new texts without feedback ($g+$ = 0.61) and on reading comprehension ($g+$ = 0.34). Additionally, larger effects of feedback on reading strategy use predicted larger effects of feedback on reading comprehension. Feedback did not have an influence on motivational aspects and also no significant effect of feedback on reading comprehension was found in these studies.

Conclusions: Feedback helps students to apply reading strategies more often and/or more efficient, even in new situations where they don't receive feedback. Students are able to transfer the practiced reading strategies to new texts, which fosters reading comprehension. With the currently available studies we did not find motivational aspects to be influenced when students received feedback during a reading task.

Keywords: feedback, reading comprehension, motivation, reading strategies, meta-analysis

Introduction

Difficulties in reading comprehension skills are a common obstacle for learning among students in all levels of education, ranging from elementary school to higher education (see e.g., Cecilia et al., 2014; Gorzycki et al., 2016; Kerr & Frese, 2017; OECD, 2018). That is, the inability to create a complete and coherent mental model of the text withholds students from being able to sufficiently understand and thereby learn from a text (see e.g., Kintsch, 1986; van den Broek et al., 2002). In order to address this issue, the development of a thorough understanding of both reading comprehension and its underlying skills as well as the effects of instruction strategies is crucial (see Israel & Reutzel, 2017). One of the vital elements of effective reading comprehension instruction is providing students with feedback in order to facilitate text comprehension (Crossley & McNamara, 2017). Decades of research have, on average, shown positive effects of feedback, i.e., individualized information in response to students' performance on assignments or questions aimed to improve learning, on reading comprehension (Swart et al., 2019). However, studies show large variances in the effects of feedback. In a recent meta-analysis, Swart et al. (2019) showed that the effect of feedback on reading comprehension differs related to two dimensions: the timing of the feedback and its richness (i.e., the amount of information provided in feedback messages). Feedback is less effective if it is provided during reading than after reading: probably because the reader is required to multitask by processing the text, the content of the feedback, and by integrating these two processes. This results in an additional load on the reader's working memory and interrupts the reading process (Sweller, 1994; Sweller et al., 1998). Additionally, the richness of the feedback influences the effect it has on reading comprehension. That is, feedback containing the correct answer or both the correct answer and hints or explanations is more effective than feedback solely stating 'right' or 'wrong'. This only holds, however, when feedback does not interrupt the reading process (i.e., is provided after reading the text). Although insight into the effects of different features of feedback is important, in order to get a thorough understanding of the effectiveness of feedback as an instructional tool, it is also crucial to investigate how feedback fosters reading comprehension. Therefore, in the present meta-analysis we aim to provide more insight in the mechanisms explaining the effects of feedback on reading comprehension. In line with the *Feedback Intervention Theory* (FIT; Kluger & DeNisi, 1996), stating that it is crucial to understand students' total reaction to feedback, not only the targeted learning outcome, when investigating the effects of feedback, we test the effects of feedback on cognitive and affective processes (i.e., the use of reading strategies and motivational aspects) that are related to reading comprehension.

From a Vygotskian perspective, feedback can be seen as a form of scaffolding aimed at reducing the gap between actual and desired performance (Bransford et al., 2000;

Sadler, 1989; Shute, 2008). In the case of reading comprehension this is the gap between a reader's current understanding of the text and a complete and coherent mental model of the text. As such, feedback has the function to inform the reader about misunderstandings that need to be corrected, to fill in gaps in understanding and/or to increase awareness of one's level of understanding (Ilies et al., 1996). Creating awareness of one's level of understanding is essential when teaching students to self-regulate (i.e., manage) their learning from texts (see Hoska, 1993; ter Beek et al., 2018). Self-regulated learning does not only require (meta)cognitive strategies such as inference making and monitoring comprehension, but also the will to learn (i.e., motivation). In a recent review on scaffolding in computer-assisted learning, Ter Beek et al. (2018) argued that effective feedback should help students to pay attention to both of these components of self-regulated learning. Likewise, Kluger and DeNisi (1996) in their FIT state that the effects of feedback on learning performance can be explained by the combination of effects on both task-learning processes and task-motivational processes. Accordingly, in the present meta-analysis we investigate the effects of feedback on the use of reading strategies (i.e., task-learning processes) and motivational aspects (i.e., task-motivational processes) related to reading comprehension.

Feedback as a Tool to Develop Reading Strategies

Effectively applying reading strategies while reading, i.e., cognitive or behavioral actions during reading aimed at improving the understanding of the text (Graesser, 2007), such as monitoring comprehension, questioning, rereading passages, making inferences during reading and the use of background knowledge, is essential for reading comprehension (see Gersten et al., 2001; Graesser, 2007; Palinscar & Brown, 1984). As a consequence, we wonder whether feedback could help readers to develop and deploy reading strategies that are needed to improve reading comprehension. Results of intervention studies indeed have shown positive effects of feedback on question-answering while reading on comprehension monitoring, self-questioning, highlighting and strategic decision making when searching for relevant information in a text (e.g., Lee et al., 2010; Llorens et al., 2014, 2016; Sung et al., 2008). Additionally, Bransford et al. (2000) state that feedback can help students to develop comprehension monitoring skills, which they can later also apply in learning situations in which they do not receive feedback.

Although several researchers have stressed the importance of instruction in reading strategies to enhance reading comprehension in both readers with and without difficulties in reading (see e.g., Crossley & McNamara, 2017; Edmonds et al., 2009; Gersten et al., 2001; Okkinga et al., 2018; The National Reading Panel, 2000), transfer of reading strategies to new texts is understudied in research on the effects of reading strategy instruction in general (Elleman & Compton, 2017) as well as in the specific case of feedback (Swart et al., 2019). Even though most studies report on the effects of strategy instruction on reading comprehension, most studies do not test transfer effects of strategy instruction (i.e., strategy use in new texts). In order to test the effects of transfer of reading strategies to new texts and in turn on reading comprehension, interventions studies must include not only reading comprehension post-tests for the texts that are used during the interventions. It is also needed to test whether practiced reading strategies are applied when students read a new text and how this relates to comprehending this new text. However, in most studies on the effects of feedback, comprehension was measured for texts that were read during the experimental reading task that included feedback.

Feedback as Motivator

Motivated readers usually have a more positive attitude towards a reading task they are performing and are more engaged during reading. As a result, they are more willing and able to invest cognitive effort in understanding the materials they are reading, which positively influences reading comprehension (Guthrie et al., 2012; Guthrie & Wigfield, 2000). This willingness to invest cognitive effort in understanding the text is especially important in educational contexts where students are required to learn from a text. Academic texts are complex and information density is high compared to narrative texts that are read for pleasure (see van den Broek et al., 2001; Wolters et al., 2017). Motivation for reading complex academic texts is not self-evident (see e.g., Coddington, 2009; Guthrie & Wigfield, 2000; Neugebauer, 2013; Pak & Weseley, 2012) and seems to diminish both during students' school careers (Jacobs et al., 2003) and in general among adolescent students over the past 20 years (OECD, 2018). It is, therefore, important to better understand whether instructional practices have an effect on motivational aspects (for better or for worse).

A diverse range of instructional practices has been shown to positively influence motivation for reading and reading engagement (Guthrie et al., 2012; Guthrie & Wigfield, 2000; van Steensel et al., 2016). As a consequence, we wonder whether feedback could help readers to be more motivated and/or engaged during reading. Kluger and DeNisi (1996) in their FIT describe motivational mechanisms underlying feedback. The fundamental assumption of the FIT is that behaviour is regulated by comparing one's current performance with goals or standards for performance. Feedback functions as a notification that helps readers comparing their current performance (i.e., level of understanding of the text) to the goal (i.e., full understanding of the text). Assuming that readers are focussed on aligning current performance with the goal, this notification motivates students to increase cognitive effort, or engagement in order to achieve full understanding of the text they are reading. Hattie and Timperley (2007) also argued that feedback can function as a motivator by providing the readers with awareness of their understanding (see also Kulhavy & Wager, 1993; ter Beek et al., 2018). They argue that this awareness increases readers' expectancies for success and self-efficacy and, at the same time, reduces feelings of uncertainty (Shute, 2008; Wigfield et al., 2016). In other words, feedback may be understood as a motivational input by providing feelings of autonomy and competence (Ryan & Deci, 2000). However, according to the FIT, if students do not believe that they are able to close the gap between current understanding and full understanding of the text or if they do not believe that the feedback is helpful in achieving full understanding of the text, feedback may also decrease motivation and reduce the cognitive effort that readers are willing to put in the reading task (Kluger & DeNisi, 1996). In other words, feedback could work both as a motivator and demotivator.

In line with the diverging motivational effects of feedback that are proposed from a theoretical point of view, the results of studies on the effects of feedback when students perform a reading task on motivational aspects, and as a consequence on reading comprehension, are mixed. Martin et al. (2007) found that feedback on comprehension questions during reading resulted in a more positive attitude towards the reading task, an increased belief in the usefulness of the reading task and increased reading comprehension compared to a control condition in which students did not receive feedback. Others showed that feedback on questions during reading did not significantly influence readers' attitudes towards the reading task in a positive or negative way, but negatively influenced reading comprehension (see e.g., Lasoff, 1981; Saunders, 1998). Jacobs and Kulkarni (1966) found that students from one junior high school rated a reading task less interesting when they received feedback on questions while performing the reading task, whereas students from another high school rated the reading task with and without feedback equally interesting. Nevertheless, feedback had a negative effect on reading comprehension in both groups.

Present Study

The aim of the present study is first to investigate whether the effects of feedback on reading comprehension can be explained by the increased use of reading strategies and by changes in motivational aspects. Second, we also wonder whether the gains in reading comprehension are greater when feedback has larger effects on the use of reading strategies or motivational aspects.

Related to the first aim, we investigate the effects of feedback on (1) the use of reading strategies when reading a new text in a reading post-test and (2) motivational aspects, reflected by readers' attitudes or engagement towards the reading task including feedback compared to the reading task without feedback. In line with previous studies on the effects of feedback on reading strategy use and reading comprehension (e.g., Bransford et al., 2000; Lee et al., 2010; Llorens et al., 2014, 2016; Sung et al., 2008), we expect feedback to have a positive impact on the use of reading strategies. In the case of motivational aspects, both a positive or negative effect of feedback could be expected. Based on theories stating that feedback could provide the reader with feelings of autonomy and competence (Locke & Latham, 1990) and the idea that feedback may reduce feelings of uncertainty (Ryan & Deci, 2000; Shute, 2009; Wigfield et al., 2016) a positive effect of feedback on motivational aspects could be expected (see also ter Beek et al., 2018). However, based on Kluger and DeNisi's reasoning (1996) that feedback could have a negative effect on motivation if it does not support readers' believes in their ability to gain full understanding of the text or that feedback itself is not a helpful tool to achieve full understanding, a negative effect of feedback could also be expected.

Second, in the case that feedback appears to have a significant effect on the use of reading strategies and/or motivational aspects, we then investigate if the effects sizes moderate the gains in reading comprehension. In other words, in line with the FIT, we test if the effect of feedback on the targeted learning outcome (i.e., reading comprehension) can be explained by cognitive processes (i.e., the use of reading strategies) and affective processes (i.e., motivational aspects) related to reading comprehension. Because of the importance of the use of reading strategies for reading comprehension (see e.g., Gersten et al., 2001; Graesser, 2007; Palinscar & Brown, 1984) and the relationship between motivation and engagement on the one hand and reading comprehension on the other hand (see e.g., Guthrie et al., 2012; Guthrie & Wigfield, 2000; Wolters et al., 2017), we propose that the strength of the effects of feedback on the use of reading strategies and/or motivational aspects could, at least partially, explain the effects of feedback on reading comprehension.

Methods

Inclusion Criteria

The present meta-analysis is performed on studies that tested the effects of feedback on questions/tasks during or directly after reading on reading comprehension and that included statistics for at least one outcome measure for the use of reading strategies when reading a new text in a reading post-test or that included statistics for motivational aspects. Additionally, reports had to meet the following criteria: (1) an intervention study was described that compared a feedback condition to a control condition in which participants read similar or comparable text but without receiving feedback on questions/task included in the reading task; (2) participants were conventional readers and read the informative or narrative texts themselves; and (3) reports had to be written in English. No restrictions were set for students' age or country or origin or publication status.

In line with Graesser's (2007) definition of reading strategies, we included all measures for the use of reading strategies related to cognitive (e.g., connecting information from the text to background knowledge) or behavioural actions (e.g., highlighting or clicking back to previously read information in order to being able to reread a passage) aimed at improving comprehension of the text. Measures could be self-reports on the use of reading strategies (e.g., Lee et al., 2010), tasks that tested the use of a specific reading strategy (e.g., use-of-strategy test, Sung et al. 2008) or behavioural data that was collected during the reading task (e.g., rereading previous pages of text, see Llorens et al. 2014; note taking or highlighting, see Lee et al., 2010). In order to investigate the effect of feedback on motivational aspects related to reading comprehension, all self-report measures that contained questions about or information on the reader's motivation, reflected by reader's attitude towards the reading task, or engagement during reading were included in the present meta-analysis. Because a universal definition of motivation and engagement is lacking in the reading literature, motivation and engagement aspects are often commingled in measurement instruments, and both concepts function highly interactive (for a review on this topic, see Unrau & Quirk, 2014), we combined these measures in the present meta-analysis.

Information Sources

A literature search was performed of more than 15,000 references to journal articles, research reports, conference proceedings, dissertations, handbooks, and book chapters published up to March 2020 in seven databases (PsycInfo, PsycArticles, ERIC, Proquest Dissertations and Theses Global, Web of Science, Linguistic and Language Behavior Abstracts and Google Scholar; see Figure 1 for an overview of the literature search). Search queries were combinations of the terms books, e-books, literacy and reading on the one hand, and feedback, scaffolding, interactivity, and tutoring on the other hand. Additionally, references of review studies, relevant handbooks, and eligible studies that we found in the online databases and publication lists of authors of reports that were included in the meta-analysis were checked. The literature search resulted in 11 study reports (see Appendix A), including 18 contrasts.

Coding Procedures

Bibliographical information, sample characteristics, and outcome measures for reading comprehension, the use of reading strategies when reading new texts, and motivational aspects, were coded for each study report and contrast by the first author and two trained undergraduate students. The students coded all reports in pairs and had to reach consensus on each coding category. Inter-coder reliability between the coding of the students and the first author was on average $\kappa = .92$ ($SD = .10$, range .77 – 1.00). In case of disagreements, the first author made a final coding decision.

Meta-Analytic Procedures

Hedges' g was calculated for the difference in mean scores between the feedback condition and the control condition. Raw means and standard deviations were used to calculate the effect sizes. A positive effect size indicated that participants applied more reading strategies when reading a new text after the feedback condition than the control condition or were more motivated (i.e., were more engaged or had a more positive attitude towards the reading task). A positive effect size for reading comprehension indicated that participants performed better on reading comprehension post-tests after the feedback condition than the control condition.

Effect sizes for all outcome measures were entered into the Comprehensive Meta-Analysis software, Version 2.0 (Borenstein et al., 2005) and inspected for outliers (standardized residuals larger than ±3.29; Tabachnick & Fidell, 2007). In the case of multiple measures for the same outcome within a contrast, effect sizes were averaged to account for dependency among the effect sizes. Subsequently, effect sizes were combined using the random effects model in order to take into account differences in reading tasks, samples and measurement instruments among the studies (Borenstein et al., 2009; Lipsey & Wilson, 2001; Shadish & Haddock, 2009; Viechtbauer, 2007), weighing effect sizes by their inverse variance. For each combined effect the 95% confidence interval was calculated and heterogeneity was estimated based on the Q-statistic (Lipsey & Wilson, 2001).

To check for publication bias, we graphically inspected funnel plots including all average effect sizes per contrast for the use of reading strategies or motivational aspects. In case of asymmetry, Duval and Tweedie's (2000) trim-and-fill procedure was used to correct for publication bias. Additionally, we checked the classic fail-safe N, applying Rosenthal's criterion (Rosenthal, 1979), stating that a minimum fail-safe N of $5k + 10$ (k = number of study contrasts) is required to consider a combined effect robust.

Because there were no studies in which measures for both the use of reading strategies and motivational aspects were included, we decided to perform two separate meta-analyses. The first on studies in which measures for the use of reading strategies when reading a new text and reading comprehension were included and the second on studies in which measures for motivational aspects and reading comprehension were included. Subsequently, in the case of a significant effect we performed a meta-regression analysis to test if the effect sizes for the effects on the use of reading strategies or motivational aspects predicted the effect sizes of the effect of feedback on reading comprehension.

Results

Descriptive Statistics

The present meta-analyses consisted of 8 contrasts that included statistics for the effects of feedback on reading strategy use when reading a new text and reading comprehension and 10 contrasts that included statistics for one or more effects of feedback on motivational aspects and reading comprehension. Inspection of all effect sizes showed no outliers.

The Effect of Feedback on the Use of Reading Strategies and Reading Comprehension

Among the 8 studies in which effects were reported on both the use of reading strategies when reading a new text and reading comprehension, feedback had a moderate positive effect on the use of reading strategies ($g^+ = 0.61$, $k = 8$, $SE = 0.22$, 95% CI = [0.17, 1.04], $p < .01$). Participants used more reading strategies after reading tasks including feedback than after control tasks without feedback. This effect was heterogeneous, Q (7) = 42.74, $p < .001$. The funnel plot for these studies showed a symmetrical pattern of effects sizes, no effects had to be imputed. Additionally, the classic fail-safe N indicated that 91 contrasts with a null-effect were needed to turn the significant effect of feedback on reading strategies into a non-significant one. Based on these statistics we concluded that the combined effect of feedback on the use of reading strategies was reliable and robust. Also, a significant positive effect of feedback on reading comprehension was found in these 8 studies ($g^+ = 0.34$, $SE = 0.09$, 95% CI = [0.17, 0.50], $p < .001$). This effect was homogeneous, Q (7) = 6.36, $p = .50$.

A meta-regression analysis showed that the magnitude of the effects of feedback on the use of reading strategies positively predicted the effect of feedback on reading comprehension (coefficient = 0.29, SE = 0.14, 95% CI = [0.01, 0.56], z = 2.04, Q = 4.14, p = .04; see Figure 2). That is, in studies in which larger effects of feedback on the use of reading strategies were found, larger effects on reading comprehension were also accomplished.

The Effect of Feedback on Motivational Aspects and Reading Comprehension

Feedback had no significant effect on motivational aspects related to reading comprehension (g^+ = 0.07, k = 10, SE = 0.26, 95% CI = [-0.44, 0.58], p = .78). On average participants were not more or less engaged or did not have a more positive or negative attitude towards the reading task if they received feedback. Also, the average effect of feedback on reading comprehension in these 10 studies was non-significant (g^+ = -0.02; SE = 0.21, 95% CI = [-0.42, 0.38], p = .93).

Discussion

Thus far, research on the effects of feedback has mainly focused on design features (e.g., timing and richness) as an explanation for variance among the effects of feedback on reading comprehension found in several studies (Swart et al., 2019). However, to achieve a thorough understanding of feedback, insight in the mechanisms explaining the effects of feedback is necessary. Therefore, to further unravel the effects of feedback on reading comprehension, in the present meta-analyses we investigated the effects of feedback on cognitive processes (the use of reading strategies) and affective processes (i.e., motivational aspects) that are related to reading comprehension. This approach is in line with the FIT (Kluger & DeNisi, 1996), stating that it is crucial to understand students' total reaction to feedback including cognitive and affective aspects in addition to the effect on the targeted learning outcome (i.e., reading comprehension). Results showed that feedback had a moderate positive effect on the use of reading strategies when reading a new text. The strength of the effect of feedback on the use of reading strategies positively predicted the effect of feedback on reading comprehension. No effect of feedback was found on motivational aspects related to reading comprehension. In these studies including motivational aspects, the effect of feedback on reading comprehension was also not significant.

The Effect of Feedback on the Use of Reading Strategies

The positive effect of feedback on the use of reading strategies when reading a new text is in line with our hypothesis based on previous research (e.g., Bransford et al., 2000; Lee et al., 2010; Llorens et al., 2014, 2016; Sung et al., 2008) and the idea that feedback helps students to shift attention to processes needed to accomplish understanding of the text (see Hoska, 1993). Readers showed (e.g., Llorens et al., 2016) and/or reported to use (e.g., Lee et al., 2010) more reading strategies after reading tasks that included feedback than after reading tasks without feedback. As was expected based on the importance of adequately using reading strategies for reading comprehension (Gersten et al., 2001; Graesser, 2007; Palinscar & Brown, 1984), this positive effect of feedback on the use of reading strategies appeared to result in better reading comprehension as well. In other words, feedback helps students to apply reading strategies more often and/or more efficient and they can apply these skills in new reading tasks where they don't receive feedback. So, they are able to transfer the practiced reading strategies to new texts. The ability to transfer the use of reading strategies to new texts also fosters reading comprehension in cases where students do not have the help of feedback. By empirically testing the results of feedback on both strategy use when reading a new text and reading comprehension, the results of the present meta-analyses contribute to an understudied area in the literature on the effects of reading strategy instruction and feedback (see Elleman & Compton, 2017; Swart et al., 2019). So far, research has mainly shown that instruction in the use of reading strategies results in improved reading comprehension, but the direct effect of reading strategy instruction on strategy use in new texts was only sparsely empirically tested. The present meta-analysis contributes to filling this gap and showed that feedback can be used as an effective tool in reading strategy instruction, thereby promoting the use of reading strategies and thus reading comprehension.

Although Swart et al. (2019) showed that feedback is most effective for supporting understanding of a text if provided directly after reading, in six out of eight contrasts in the present meta-analysis feedback was provided during reading. Possibly, feedback during reading is less effective in supporting the understanding of a text 'on the job' (i.e., understanding of the text that a student is currently reading), but might facilitate the teaching of reading strategies that students can use in new texts in which they do not receive feedback. Answers and explanations in feedback messages might function as a model for readers on how to effectively integrate information in the text into a coherent mental model, comparable to modelling approaches in reading comprehension instruction (see Afflerbach et al., 2020; Duke & Pearson, 2008). As a consequence, future research should focus on the effects of different features of feedback (e.g., richness and timing) in relation to these two functions of feedback: feedback as a tool to support understanding of a text ‘on the job’ and feedback as a tool for reading strategy instruction to foster reading comprehension skills that could be transferred to contexts in which the reader does not receive feedback.

The results of the present study have to be interpreted with some caution. Due to the wide variety in primary studies on the effects of feedback we were only able to include eight studies in which effects of feedback on both strategy use and reading comprehension were included. However, the found effect of feedback on the use of reading strategies is robust as the fail-safe *N* indicated that 91 contrasts with a null-effect are needed to turn the significant effect of feedback on reading strategies into a non-significant one (see also Fragkos et al., 2014). As a consequence of the limited number of studies, we were not able to investigate the interplay of design features of feedback (e.g., timing and richness) and the two different instructional perspective (i.e., feedback as support for reading comprehension ‘on the job’ and feedback as an instructional tool to teach reading comprehension skills). Additionally, although reading comprehension difficulties are common in all levels of education, future research should focus on how to best support and teach reading comprehension in different age groups of students. Due to the limited number of studies, we were not able to draw conclusions on this matter in the present meta-analysis.

The Effect of Feedback on Motivational Aspects

Theoretical perspectives on the motivational effects of feedback considered both positive effects and negative effects. Based on the goal-setting theory and control theory (see Kluger & DeNisi, 1996), stating that feedback provides the reader with feelings of autonomy and competence (Locke & Latham, 1990) and the idea that feedback may reduce feelings of uncertainty (Ryan & Deci, 2000; Shute, 2008; Wigfield et al., 2016) a positive effect of feedback on motivational aspects could be expected (see also ter Beek et al., 2018). However, based on Kluger and DeNisi’s reasoning (1996) that feedback could also have a negative effect on motivation if it does not support readers’ believes in their ability to gain full understanding of the text or that feedback itself is not a helpful tool to achieve full understanding, a negative effect of feedback could also be expected. Results of the present meta-analysis showed that participants were on average not more engaged or did not rate the reading tasks more positively or negatively when these included feedback. In other words, based on the available research we cannot conclude if feedback functions as a motivator or as a demotivator.

Possibly, the lack of a motivational effect in the present study is a consequence of the fact that we could not distinguish between good and poor performing students during the intervention. In line with Kluger & DeNisi's (1996) FIT, feelings of autonomy and competence might only increase when the gap between the actual and desired performance can be bridged by the feedback (see also Bransford et al., 2000; Sadler, 1989; Shute, 2008). For poor performers the gap might be too large with the result that feedback mainly notifies them of errors and/or gaps in understanding. Also, research has shown that students particularly allocate attention to feedback on incorrect answers. As a consequence, poor performing students spend more time on negative feedback than good performing students (see Máñez et al., 2019), which has been shown to decrease motivation (Fong et al., 2019). In sum, possibly the combination of motivating and demotivating effects that have been found in different subgroups of students could have resulted in the average null-effect that was found in the present study.

Additionally, the questionnaires used in the primary studies targeted a wide range of motivational aspects ranging from interest and engagement (e.g., Jacobs & Kulkarni, 1966) to participants' attitudes towards learning experiences (i.e., perceived usefulness; Chen et al., 2011) and teaching methods or programs used for the reading tasks (e.g., "I would enjoy using other computer programs like this one in future lessons"; Martin et al., 2007). In future research, features of feedback should be systematically tested in relation to different motivational mechanisms (i.e., motivation, interest, engagement, attitude) and how these affect different groups of students (e.g., good and poor comprehenders, see Máñez et al., 2019). Insight in these motivational processes may also further unravel why, on average, no effect of feedback on reading comprehension was found in the studies included in the present meta-analysis.

Conclusions

In the present meta-analysis we aimed to explain the effects of feedback by unravelling the effects of feedback on the use of reading strategies and motivational aspects related to reading comprehension. On the one hand, combining the results of 8 studies that measured the effects of feedback on both the use of reading strategies and reading comprehension showed that feedback positively influenced readers' ability to deploy reading strategies even in situations where they don't receive feedback. This transfer of reading strategy skills consequently related to improved reading comprehension. On the other hand, combining the results of 10 studies that included information on the effects of feedback on both motivational aspects and reading comprehension showed that feedback did not function as motivational input for the readers. Readers were neither more nor less motivated, engaged or positive towards the reading tasks. Also, no effect of feedback on reading comprehension was found in these studies. Although the number of studies in the present meta-analysis is limited, the presented effect of feedback on the use of reading strategies appeared to be robust. As a consequence, the present study extends prior research on the effects of feedback on reading comprehension and should be interpreted as a starting point for future research on the use of feedback as an instructional tool to support and teach reading comprehension.

Table 1

Overview of Studies Included in the Meta-Analysis

Authors	Year	*N* feedback	*N* control	Age group	Outcome	Effect size (Hedges'*g*)
Chen et al.	2011A	19	19	Students	Comprehension	0.05
					Motivation	-0.20
Chen et al.	2011B	20	20	Students	Comprehension	0.67
					Motivation	0.29
Jacobs & Kulkarni	1966A	15	12	Secondary	Comprehension	-0.91
					Motivation	-1.47
Jacobs & Kulkarni	1966B	19	9	Secondary	Comprehension	-0.39
					Motivation	0.05
Lasoff	1981	12	12	Students	Comprehension	-0.32
					Motivation	0.28
Lee et al.	2010	74	74	Students	Comprehension	0.54
					Strategy use	1.56
Llorens et al.	2014A	30	14	Secondary	Comprehension	0.67
					Strategy use	0.80
Llorens et al.	2014B	34	14	Secondary	Comprehension	0.35
					Strategy use	0.28
Llorens et al.	2016A Exp. 1	51	25	Secondary	Comprehension	0.10
					Strategy use	-0.17
Llorens et al.	2016B Exp. 1	41	25	Secondary	Comprehension	0.16
					Strategy use	0.37
Llorens et al.	2016C Exp. 2	38	37	Secondary	Comprehension	0.05
					Strategy use	0.10
Martin et al.	2007	43	43	Students	Comprehension	1.11
					Motivation	1.53
Saunders	1998A	17	17	Students	Comprehension	-0.14
					Motivation	-0.03
Saunders	1998B	17	17	Students	Comprehension	-0.44
					Motivation	0.01
Sung et al.	2008A	31	35	Primary	Comprehension	0.22
					Strategy use	0.89
Sung et al.	2008B	34	30	Primary	Comprehension	0.54
					Strategy use	0.97
Wentling	1973A	39	19	Secondary	Comprehension	0.17
					Motivation	0.55

Authors	Year	*N* feedback	*N* control	Age group	Outcome	Effect size (Hedges' *g*)
Wentling	1973B	39	20	Secondary	Comprehension	-0.31
					Motivation	-0.54

Note. Students = (university or college) students, Primary = primary school children, Secondary = secondary school children

Figure 1

Flow Diagram of the Literature Search Process

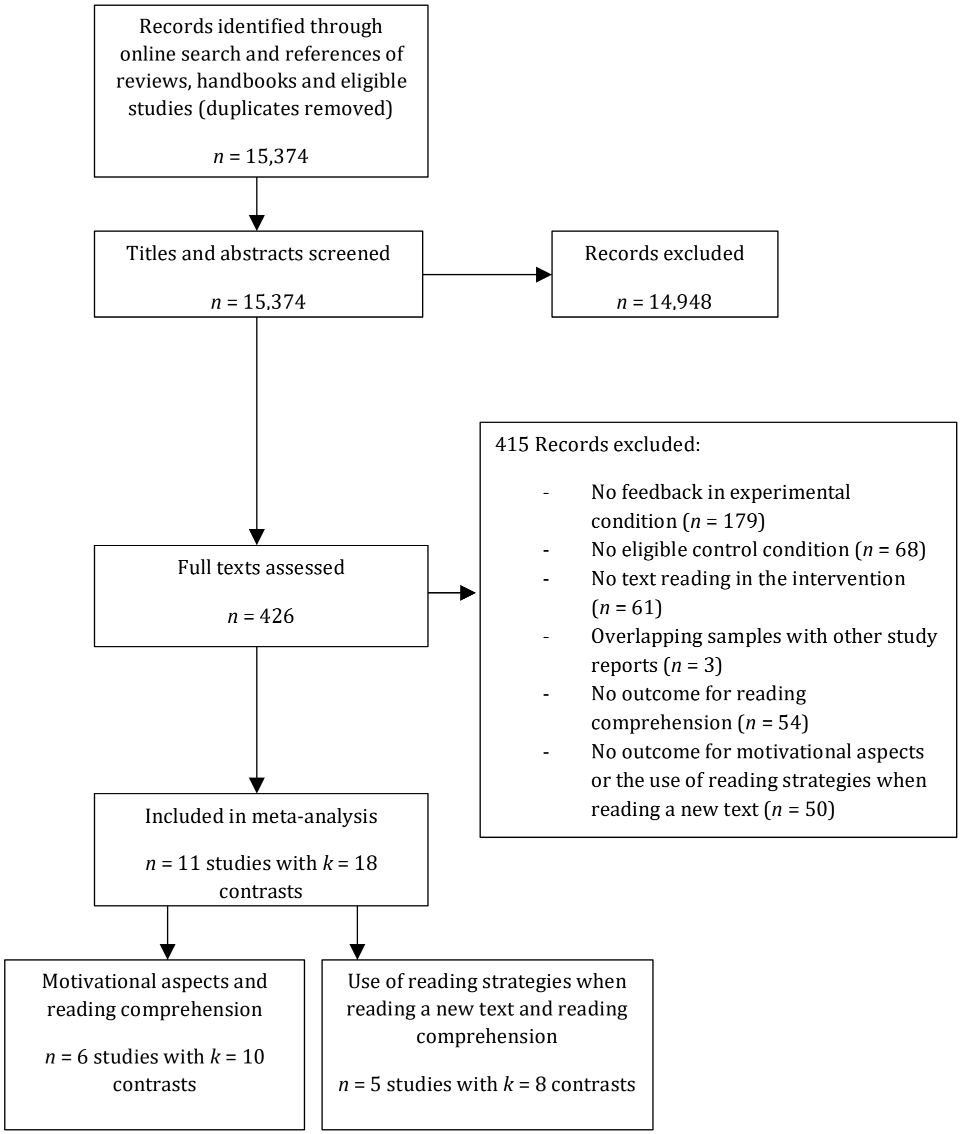
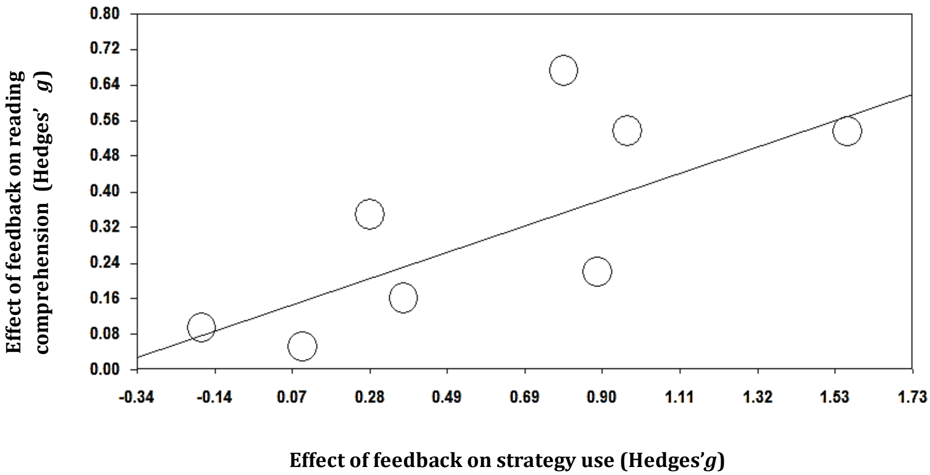


Figure 2

Results of Meta-Regression Analysis (k=8) of the Magnitude of the Effect of Feedback on the Use of Reading Strategies as Predictor of the Effect of Feedback on Reading Comprehension.



Appendix A

References of Studies Included in the Present Meta-Analysis

Chen, N. S., Teng, D. C. E., & Lee, C. H. (2011). Augmenting paper-based reading activity with direct access to digital materials and scaffolded questioning. *Computers & Education, 57*(2), 1705-1715. doi:10.1016/j.compedu.2011.03.013

Jacobs, P. I., & Kulkarni, S. (1963). A test of some assumptions underlying programed instruction. *Psychological Reports, 18,* 103-110. doi:10.1002/j.2333-8504.1963.tb00495.x

Lasoff, E. M. (1981). *The effects of feedback in both computer-assisted instruction and programmed instruction on achievement and attitude* (Publication No. 8121115) [Doctoral dissertation, University of Miami]. ProQuest Dissertations and Theses.

Lee, H. W., Lim, K. Y., & Grabowski, B. L. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development, 58*, 629-648. doi:10.1007/s11423-010-9153-6

Llorens, A. C., Cerdán, R., & Vidal-Abarca, E. (2014). Adaptive formative feedback to improve strategic search decisions in task-oriented reading. *Journal of Computer Assisted Learning, 30*(3), 233-251. doi:10.1111/jcal.12050

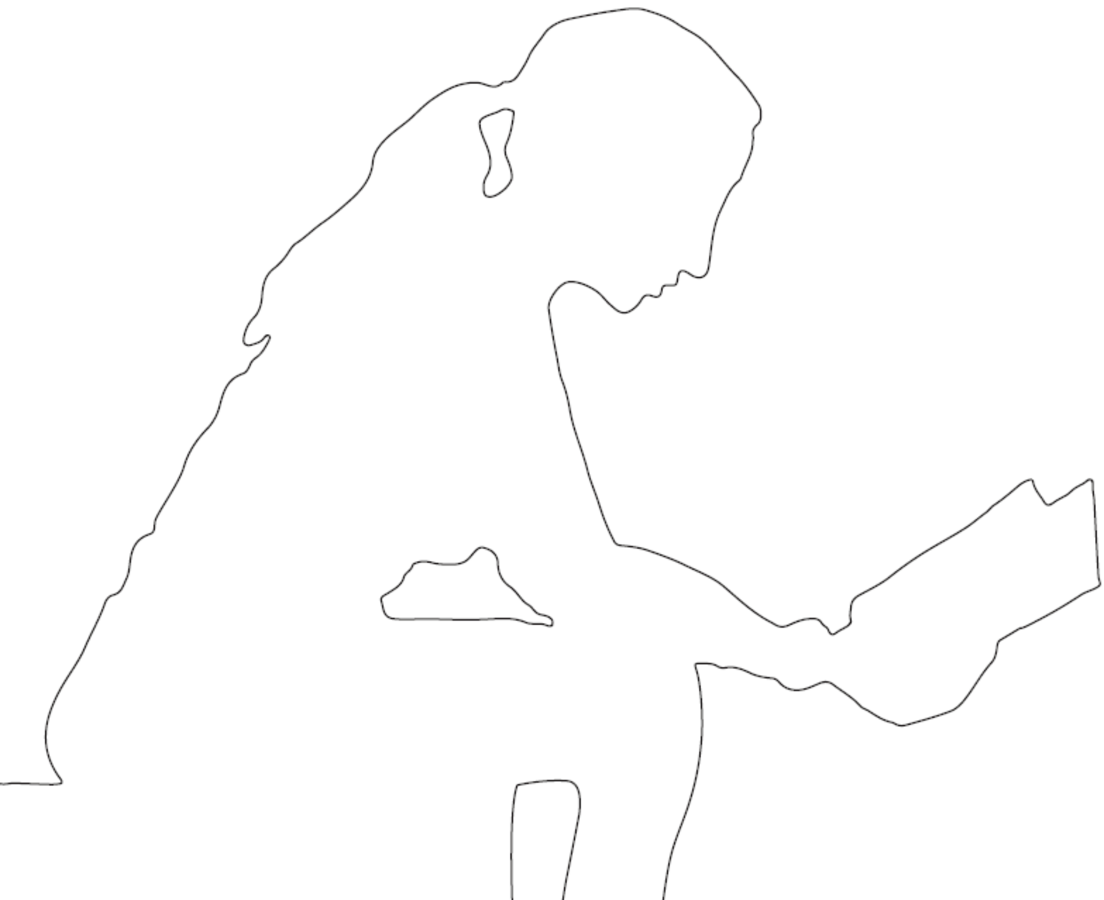
Llorens, A. C., Vidal-Abarca, E., & Cerdán, R. (2016). Formative feedback to transfer self-regulation of task-oriented reading strategies. *Journal of Computer Assisted Learning, 32*, 314-331. doi:10.1111/jcal.12134

Martin, F., Klein, J. D., & Sullivan, H. (2007). The impact of instructional elements in computer-based instruction. *British Journal of Educational Technology, 38*, 623-636. doi:10.1111/j.1467-8535.2006.00670.x

Saunders, P. H. (1998). *The effectiveness of paraphrasing and feedback in computer-based instruction* (Publication No. 9905104) [Doctoral dissertation, University of Memphis]. ProQuest Dissertations and Theses Global.

Sung, Y. T., Chang, K. E., & Huang, J. S. (2008). Improving children's reading comprehension and use of strategies through computer-based strategy training. *Computers in Human Behavior, 24,* 1552-1571. doi:10.1016/j.chb.2007.05.009

Wentling, T. L. (1973). Mastery versus nonmastery instruction with varying test item feedback treatments. *Journal of Educational Psychology, 65,* 50-58. doi:10.1037/h0034820



Chapter 6

Summary and General Discussion

Although reading comprehension is an essential skill for success in academic, professional, and private life, a substantial number of students at all levels of education experience difficulties in reading comprehension (see e.g., Andrianatos, 2019; Bettinger & Long, 2009; Gorzycki et al., 2016; OECD, 2019). These students are unable to create a complete and coherent mental model of a text (Kintsch, 1986). Creating a complete and coherent mental model of a text is a complex task, requiring the reader to regulate attention in order to continuously select information from the text (Arrington et al., 2014; Georgiou & Das, 2016) and to make inferences that connect pieces of information within and across sentences in the text, and connect text information to background knowledge (Graesser et al., 1994; Kintsch, 1988).

Given the complex nature of reading comprehension, it follows that understanding comprehension requires a multifaceted approach, one that focuses on the multiple skills and processes necessary for comprehension to occur (Israel & Reutzel, 2017). Insight into such skills and processes is fundamental to (1) understanding individual differences in reading comprehension and (2) developing effective methods for improving reading comprehension (see Castles et al., 2018; Hoffman, 2017; Israel, 2017; Kendeou et al., 2014; McNamara & Kendeou, 2011). Both of these knowledge aims are an indispensable part of the ongoing mission of reading researchers, who endeavour to enhance students' reading comprehension skills and prevent students from developing reading comprehension difficulties. A multifaceted approach to understanding reading comprehension incorporates understanding both the internal factors (i.e., individual differences in reading comprehension and underlying skills) and external factors (i.e., methods for improving reading comprehension) that are related to reading comprehension, and necessitates a methodologically diverse approach to the research.

The research in this dissertation represents a multifaceted approach to understanding reading comprehension processes, and employs diverse methodologies to examine both internal and external factors related to comprehension. More specifically, the research addresses attentional control processes during reading, the influence of dopamine on both attentional control and reading comprehension (i.e., internal factors; Chapter 2 and 3), and the effects of feedback on both reading comprehension and on cognitive and affective processes related to reading comprehension (i.e., external factors; Chapter 4 and 5).

In the following sections, the main findings of the studies described in Chapter 2, 3, 4, and 5 are summarized, integrated and discussed. This is followed by a consideration of directions for future research and implications for practice.

Attentional Control and Reading Comprehension

Present day students grow up in a world in which focusing attention is an ever more challenging activity, a world in which the ever expanding features of digital devices and platforms and their easy accessibility result in a non-stop call for attention (see Gazzaley & Rosen, 2016; Rosen, 2017; van der Stigchel, 2018). Resisting this distracting information has been posed as one of the fundamental challenges of reading and understanding texts in our present-day society (Alexander, 2020). Some even refer to the present-day society as the '*age of distraction*,' or '*the attention economy*,' or state that our society is in '*an attentional crisis*' (see Crawford, 2015; Furedi, 2016; van der Stigchel, 2018).

For reading comprehension, it is critical that readers resist distractions from the outside as well as from the inside (i.e., distracting thoughts), focusing their attention on relevant information in the text in order to form a mental representation of the text. The ability to focus attention and resist distractions is referred to as attentional control (e.g., Arrington et al., 2014; Barrett et al., 2004). In her newest book *Reader, come home: The reading brain in a digital world*, reading researcher Maryanne Wolf (2018) discusses how the present day society may negatively influence our ability to control attention, thereby attenuating 'deep reading' abilities that are necessary for reading comprehension.

The aim of Chapter 2 of this dissertation was to examine the role of attentional control during reading in reading comprehension, and to investigate two different methods for measuring attentional control. Because the use of self-reports to measure attentional control during reading has serious drawbacks, we examined the potential for using a more objective and potentially more ecologically valid measure: frontal theta/beta ratio (TBR). The research extends previous research examining frontal TBR in relation to attentional control (Braboszcz & Delorme, 2011; van Son et al., 2019a) by adding information about frontal TBR in relation to state attentional control during reading.

Results of Chapter 2 showed that frontal TBR during reading and during a baseline resting condition were strongly related to each other. Also, frontal TBR during reading was moderately related to self-reported attentional control in daily life, although this relation was only marginally significant. In other words, the results demonstrated that attentional control during reading (i.e., state attentional control) was related to attentional control in a resting condition and to attentional control in daily life (i.e., trait attentional control). Additionally, fluctuations in frontal TBR during reading were related to self-reported mind wandering during reading, indicating that fluctuations in frontal TBR during reading reflect meaningful differences in attentional control (i.e., lapses in attentional control). In conclusion, the results of this study provide support for the suitability of frontal TBR as a biophysiological marker for state attentional control.

To test the predictive validity of frontal TBR as a measure of attentional control during reading, we used frontal TBR to predict reading comprehension. Results showed that the average frontal TBR during reading significantly predicted reading comprehension in a complex text. Students with a lower average frontal TBR during reading, indicating better attentional control, scored higher on reading comprehension. Additionally, the average frontal TBR during reading mediated the relation between baseline frontal TBR and reading comprehension. This mediation model revealed that attentional control in general (i.e., trait attentional control) is related to reading comprehension only through attentional control during reading (i.e., state attentional control). This mediation model was non-significant when reading a simple text.

The Influence of Dopamine on Attentional Control During Reading and Reading Comprehension

Whereas the study reported in Chapter 2 was aimed at gaining insight into the role of attentional control in reading comprehension by investigating methods to measure attentional control during reading, the study reported in Chapter 3 was aimed at gaining insight into individual differences in attentional control during reading and reading comprehension by investigating the neurobiological – particularly dopaminergic – processes underlying both attentional control and reading comprehension. Dopamine (DA) has been shown to play a key role in attentional control processes (see e.g., Boulougouris & Tsaltas, 2008; Braver & Cohen, 2000; Westbrook & Braver, 2016) as well as memory formation (see e.g., Adcock et al., 2006; Boulougouris & Tsaltas, 2008; Braver & Cohen, 2000; González-Burgos & Feria-Valesco, 2008; Grossman et al., 2001; Joensson et al., 2015; Kischka et al., 1996; Nieoullon, 2002). Yet, research on the effects of increased levels of DA on attentional control processes and memory formation have produced diverse results (Breitenstein, Flöel et al., 2006; Diamond et al., 2004; Knecht et al., 2004; Ko et al., 2009; Linssen et al., 2014; Zhang et al., 2015). A possible explanation for the mixed results is the inverted U-shape theory (see e.g., Cools & Robbins, 2004; Gibbs & D'Esposito, 2005).

According to the inverted U-shape theory, the relation between DA levels in the brain and cognitive performance follows an inverted U-shape, meaning that both too high and too low levels of DA can hinder cognitive performance. However, this theory does not explain the positive effects of pharmacologically increasing DA on memory performance that have been found in studies with healthy adults (see Breitenstein, Floël et al., 2006; Knecht et al., 2004), who are assumed to have a well-functioning DA system. In other words, DA levels for healthy adults are expected to be near or at the top of the inverted U-shape. As a consequence, a direct test for the inverted U-shape theory is needed.

In order to directly test the inverted U-shape theory, a randomized placebo-controlled trial was performed in which the effects of administering levodopa, a precursor of DA in the brain, on attentional control and reading comprehension were investigated in two subgroups of students: a group of students carrying the DRD4 7-repeat allele (DRD4 7+) and a group of students not carrying the DRD4 7-repeat allele (DRD4 7-). The DRD4 7-repeat allele is related to less efficient DA transmission in the brain, which results in lower levels of DA (Ariza et al., 2012; Schoots & van Tol, 2003). The logic behind the inclusion of these two groups of students, one group that was expected to have lowered levels of DA in the brain and one group that was expected to have more optimal levels of DA, was to directly test the inverted U-shape theory. In line with the inverted U-shape theory, we hypothesized that we would find an interaction effect of DRD4 genotype by treatment condition on cognitive performance. First, we tested the effects of administering levodopa on attentional control during reading. We used the objective EEG-measure (frontal TBR during reading) examined in Chapter 2, and a retrospective self-report of attentional control that did not interrupt the reading process. Second, we investigated the effects of administering levodopa on reading comprehension.

Contrary to what we had expected results of the study reported in Chapter 3 revealed no difference in the effect of increased DA on attentional control or reading comprehension between students who did or did not carry the DRD4 7-repeat allele, suggesting that the dopamine levels of students from the DRD4 7+ and DRD4 7- groups on average did not differ with regard to the position on the inverted U-shape. In addition, pharmacologically increasing DA had no effect on one of the three attentional control measures (the average frontal TBR during reading, fluctuations in frontal TBR during reading, and an attentional control self-report). However, increased levels of DA did influence reading comprehension, but this influence was negative in both groups (DRD4 7+ and DRD4 7-). That is, students performed more poorly on reading comprehension tasks in the levodopa condition than in the placebo condition. These results are in contrast to results found in word-learning studies in which healthy subjects who were administered levodopa were found to learn new words faster and better (see Breitenstein, Floël et al., 2006; Knecht et al., 2004).

In short, although the ability to attentively read and understand texts is crucial for success in academic, professional and personal life, pharmacologically optimizing attentional control and reading comprehension is a complex issue. Several results of the study described in Chapter 3 supported this notion of complexity. First, students carrying the DRD4 7-repeat allele were not more susceptible for the possible positive effects of administering levodopa. This discrepancy between the study results and our expectations might suggest that dopamine receptor genes other than the DRD4 receptor gene play a more crucial role in attentional control and reading comprehension. Alternatively, it could be that because of the cognitively high-functioning sample (i.e., the participants in the study were university students), the DRD4 genotype had less of an influence than expected. Second, the effects of increased DA levels in the brain were not detectable with our measures of attentional control during reading, but negatively influenced reading comprehension. As an explanation for this discrepancy, our attentional control measures might not have been sensitive enough. Another possibility is that DA administration has a stronger influence on memory formation than on attentional control (see Cools & D'Esposito, 2011). Third, both attentional control and reading comprehension are cognitive processes that appeal to a broad range of brain areas (Shaywitz & Shaywitz, 2008). Research has shown that different brain regions are differently susceptible to fluctuations in DA levels. For example, frontal brain regions, which play an important role in both attentional control and reading comprehension, have been shown to be particularly susceptible to fluctuations in DA levels when compared to more posterior brain regions (see Cools & D'Esposito, 2011). The complex interplay between the DA levels in different brain regions related to attentional control and reading comprehension, might have confounded the results of our study.

The aim of the study described in Chapter 3 was to gain a deeper understanding of the neurobiological processes underlying attentional control and reading comprehension through *pharmacologically* manipulating DA levels in the brain. DA levels in the brain can also be manipulated by *instructional* methods such as giving feedback (see Klein et al., 2007; Smillie et al., 2011; Ullsperger, 2010). The study reported in Chapter 4 was therefore focused on meta-analysing the effect of this instructional method on reading comprehension.

The Effect of Feedback on Reading Comprehension

A large number of studies have examined the effects of feedback on students' learning performance. Inspection of these studies reveals considerable variability in how feedback is designed and provided to students, and, perhaps because of this, variability in the effects of feedback on students' learning performance. Furthermore, meta-analyses on the effects of feedback typically summarize findings across learning tasks, making it difficult to draw reliable conclusions for specific types of learning tasks such as reading comprehension (see e.g., Azevedo & Bernard, 1995; Hattie 2012; Jaehnig & Miller, 2007; Kluger & DeNisi, 1996; Kulhavy, 1977; Shute, 2008; van der Kleij et al., 2012, 2015).

In the meta-analysis reported in Chapter 4, we first investigated the overall effect of feedback on learning from text. Next we investigated the relative effects of three design features of feedback: the *timing* of the feedback, the *richness* of the feedback, and the *means for providing* feedback to the reader.

With respect to the *timing* of the feedback, we compared feedback provided during reading with feedback provided directly after finishing the reading task. Feedback that is given during reading interrupts the reading process and requires the reader to multitask by processing information from the text he or she is reading on the one hand and processing the feedback message on the other hand. Consequently, we hypothesized that providing feedback during reading might have a negative effect on text comprehension whereas providing feedback after reading might facilitate comprehension.

With respect to the *richness* of the feedback, we compared the effects of feedback messages that differed in the richness of information. Researchers have examined the extent to which feedback should include (1) information about the accuracy of the answer only (i.e., a right/wrong statement which is considered the least rich), (2) the correct answer, or (3) explanations or elaborations in addition to the correct answer (which is considered the most rich). The literature on the influence of the amount of information included in the feedback is mixed, with some studies showing positive effects of increased richness of feedback on reading comprehension (e.g., van der Kleij et al., 2012) while other studies show no relation between the richness of feedback and reading comprehension (e.g., Golke et al., 2015; Llorens et al., 2014).

Finally, with respect to *means of providing feedback,* we compared the effects of computer-delivered feedback with non-computer-delivered feedback. Feedback studies have dated back to the 20th century and the means available for providing feedback have changed dramatically over time. The emergence of computer applications for reading instruction have created a wealth of possibilities for providing feedback in multiple modalities (e.g., text, audio, visuals, or a tutor on screen) and in spatially and temporally integrated formats.

The results of the meta-analysis reported in Chapter 4 revealed that, on average, providing students with feedback supported learning from text. Although the effect was small, variance in the magnitude of the effects was large. Moderator analyses showed that feedback was especially effective in supporting learning from text when it was provided after reading the text and contained, at the very least, the correct answer (i.e., either the correct answer alone or the correct answer + elaborated feedback). Effect sizes ranged from moderate to large, indicating that correct answer feedback and elaborate feedback are particularly effective in supporting learning from text compared to feedback that includes only a right/wrong statement. We conjectured that feedback provided after reading was more effective than feedback provided during reading because feedback provided during reading places extra demands on working memory, forcing the reader to switch attention between reading the text and processing the provided feedback. Finally, computer-delivered feedback was found to be more beneficial for learning from text than non-computer-delivered feedback, possibly because non-computer-delivered feedback places higher demands on working memory than computer-delivered feedback.

In short, when developing or choosing (educational technologies for) instructional strategies for supporting learning from text, the results of the meta-analysis reported in Chapter 4 indicate that it is best to minimally interrupt the reading process, and to ensure that feedback includes, at the very least, the correct answer, but preferably also includes additional explanations or information. Such feedback can help readers to evaluate and, if necessary, revise their mental models of a text, thereby improving their comprehension of the text.

Cognitive and Affective Processes That Might Explain the Effect of Feedback on Reading Comprehension

Whereas the meta-analysis reported in Chapter 4 was executed to gain insight in design features of feedback that might explain how feedback fosters reading comprehension, the meta-analyses reported in Chapter 5 were executed to gain insight into the cognitive and affective mechanisms that might explain how feedback fosters reading comprehension. In line with the *Feedback Intervention Theory* (FIT; Kluger & DeNisi, 1996), we argued that it was not only important to focus on learning performance (i.e., the outcome of learning), but also on the cognitive and motivational processes (i.e., affective processes) underlying learning.

An essential cognitive process that takes place during reading is the use of reading strategies (Graesser, 2007). For example, in order to achieve understanding of a text, readers need to monitor comprehension, ask questions, reread passages, make inferences and use background knowledge (see Gersten et al., 2001; Graesser, 2007; Palinscar & Brown, 1984). Additionally, affective processes, such as motivation, attitude and engagement, help readers to invest cognitive effort in understanding the text they are reading. This willingness to invest cognitive effort in understanding the text is especially important in instructional contexts in which students are required to learn from academic texts that are often complex and have high information density (see van den Broek et al., 2001; Wolters et al., 2017).

Two meta-analyses were performed to, first, test the effect of feedback on the use of reading strategies, and, second, test the effect of feedback on various motivational aspects related to reading comprehension. Subsequently, in cases where feedback significantly impacted the use of reading strategies and/or motivational aspects, we investigated whether the effect of feedback on reading comprehension could be explained by the effect of feedback on the use of reading strategies and/or motivational aspects.

Results revealed that feedback positively influenced readers' abilities to deploy reading strategies, and these effects transferred to texts where readers did not receive feedback. This transfer of reading strategy skills consequently was related to improved reading comprehension. Feedback had no influence on task-motivational processes (i.e., motivation, attitude or engagement). For the studies in which the effects of feedback on task-motivational processes were reported, there was also no effect of feedback on reading comprehension. Although the numbers of studies in the meta-analyses described in Chapter 5 were limited, the effect of feedback on the use of reading strategies was found to be robust.

In short, the results of the meta-analyses reported in Chapter 5 showed that feedback appeared to rather function as a tool to enhance the cognitive processes during reading than as motivational input. The ability of feedback to stimulate cognitive processes during reading, specifically the use of reading strategies, was apparent in texts where students did not receive feedback, showing the power of feedback to enhance reading strategy skills that readers can then transfer to new contexts.

Directions for Future Research and Practical Implications

The results of the studies described in this dissertation contribute to the literature on both internal and external factors related to reading comprehension. The dissertation takes a multifaceted perspective and uses a methodologically diverse approach to (1) gain a more thorough understanding of reading comprehension and its underlying skills and processes, including attentional control, the use of reading strategies, and motivation, and (2) develop effective methods for improving reading comprehension. In the following sections, directions for future research and practical implications in relation to optimizing reading comprehension are discussed.

Measuring and Monitoring Attentional Control During Reading

The study described in Chapter 2 presented preliminary data on the relation between frontal TBR during reading and attentional control, and the relation between attentional control and reading comprehension. Although the study included a small sample and only two narrative texts, the promising effect sizes demonstrated the potential for frontal TBR to be used as a biophysiological marker for attentional control during reading. The results suggested that both the average frontal TBR, as well as fluctuations in frontal TBR during reading, were potentially meaningful indicators. In other words, the results of Chapter 2 showed that frontal TBR could be informative in two ways: (1) the average frontal TBR during reading could potentially be used as a general indicator of attentional control during reading and (2) fluctuations in frontal TBR during reading could potentially be used as an indicator of meaningful real time information about the state of readers' attentional control.

As was discussed in Chapter 3, a drawback of using average frontal TBR as a general indicator of attentional control may be that the measure becomes less informative as the length of texts increases. Longer tasks might evoke more lapses of attention (see Krimsky et al., 2017). As a consequence, ups and downs in attentional control may average out in the overall average frontal TBR over the entire text. Future research should focus on replicating the relations found in Chapter 2 using different types and lengths of texts and among different populations (e.g., students suffering from ADHD).

Portable and wireless applications for EEG offer low-cost options for implementing brain-computer interfaces into reading research and investigating their added value for instructional purposes. However, the EEG-devices and EEG-indexes that are used in research with brain-computer interfaces to monitor attention during reading and other learning tasks vary broadly (see e.g., Chen & Huang, 2014; Xu & Zhong, 2018). As a consequence, more research is needed to gain a deeper understanding into which indices could be most informative about the attentional control state of students during reading.

In fact, as a follow-up to the research reported in Chapter 2 and a starting point for developing instructional tools to support attentional control during reading, we currently are conducting two small-scale exploratory studies to examine the potential for using frontal TBR as a real-time indicator of attentional control during reading. In these studies, we monitor attentional control during reading by recording frontal TBR with a Neurosky wireless and portable EEG-headset while students read an expository text. In these studies we use two types of apps. In the first study, we use an app that monitors frontal TBR during reading, but does not notify the reader of fluctuations in frontal TBR. In the second study, we use an app that monitors frontal TBR during reading and notifies readers when frontal TBR drops. When using this second app, readers received feedback on their state of attentional control.

The development of instructional tools to support readers in controlling their attention during reading could particularly be helpful for groups of students who are vulnerable for attentional control problems, such as students with ADHD. ADHD has been found to co-occur with difficulties in reading comprehension (see e.g., Brock & Knapp, 1996; Flory et al., 2006) and ultimately to academic underachievement that may persist into young adulthood (see e.g., Miller et al., 2012; Weyandt & DuPaul, 2008). Reducing reading comprehension problems by training and guiding attentional control during reading might diminish academic underachievement. However, the practicalities of using frontal TBR as an instructional tool, and the actual influence on students' reading comprehension, must be tested in future research.

Supporting Reading Comprehension 'on the Job' vs. Teaching Reading Comprehension Skills

Results of the meta-analysis reported in Chapter 4 demonstrated that interrupting reading with feedback places an extra burden on cognitive resources, cancelling out the potentially positive effect that feedback might have. These results imply that interventions aimed at supporting reading comprehension should minimally interrupt the natural reading process. That said, integrating the results of the meta-analyses in Chapter 4 and 5 suggests that interruptions during reading can serve an instructional purpose. The results of the meta-analyses described in Chapter 5 showed that feedback was effective in promoting transfer of the use of reading strategies to new texts for which no feedback was provided. In other words, feedback helped students to develop reading strategy skills and to apply these skills in new contexts, thereby improving reading comprehension. As a consequence, it seems that the effects of feedback should be investigated in two instructional contexts: (1) the use of feedback to support reading comprehension 'on the job' (i.e., promoting reading comprehension, and thereby learning from the particular text that is read while receiving feedback) and (2) the use of feedback as an instructional tool for teaching reading comprehension skills (i.e., promoting reading comprehension by enhancing reading strategy skills that could be transferred to situations in which students do not receive feedback while reading).

Future research on the use of feedback to support or teach reading comprehension should not only distinguish between these two instructional contexts, but also extend insights into the effectiveness of design features of feedback presented in the present dissertation. In other words, future research should separately investigate the effects of design features of feedback (i.e., timing, richness, means of providing feedback etc.) in two instructional contexts, namely on- and off the reading job. As a consequence of the limited number of studies that could be included in the meta-analyses reported in Chapter 5 and the overlap in design features in the studies included in these meta-analyses, this simultaneous differentiation in learning contexts and design features could not be realized. The majority of studies in Chapter 5 included feedback that was provided during reading. Additionally, for three quarters of these studies, the feedback provided was elaborated feedback. Alternatively, 10 out of 11 studies that tested the effects of feedback on motivational aspects related to reading comprehension included feedback that contained the correct answer or only a simple right/wrong statement. These types of feedback could be less informative for students, thereby being less helpful in correcting inadequate mental representations of a text. This could have possibly explained why no effect of feedback was found on motivational aspects.

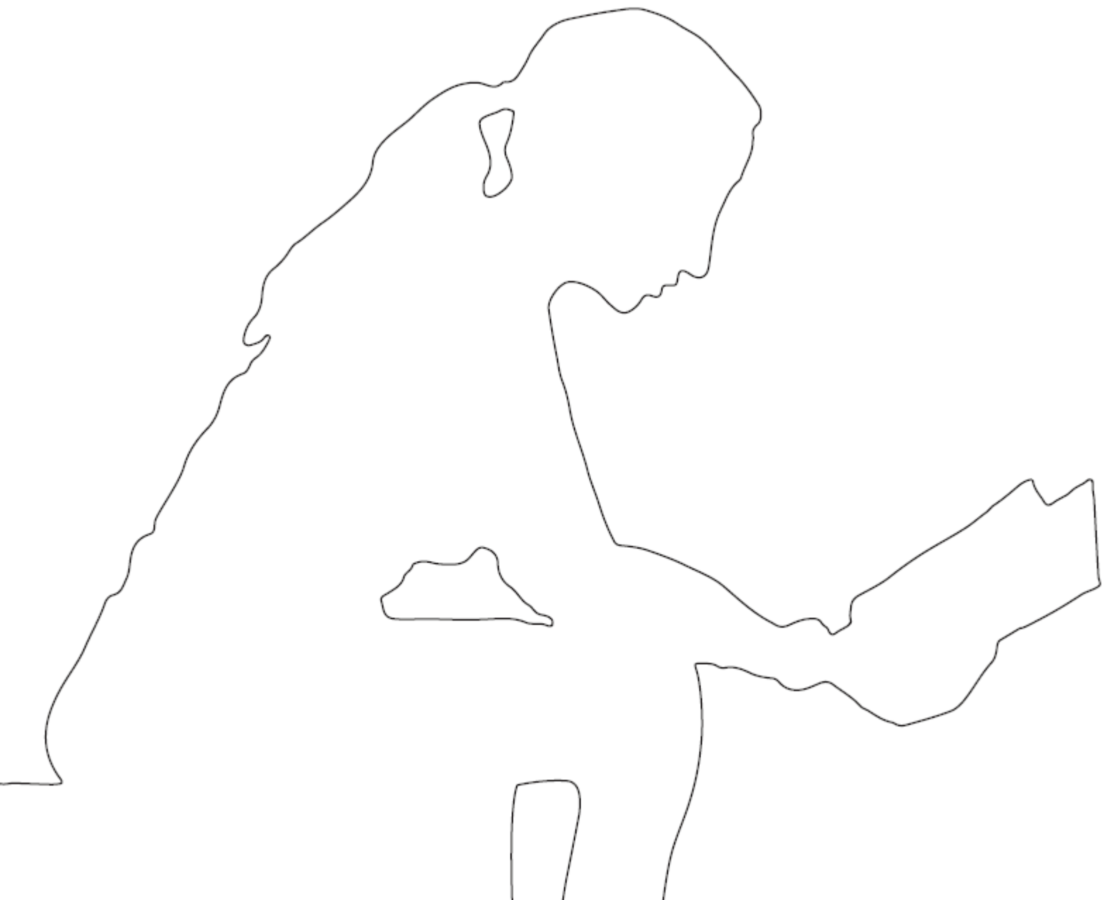
Another factor that should be taken into account when further investigating the effects of feedback is the age and/or reading level of students. Moderator analyses in Chapter 4 showed that secondary school students benefitted the least from feedback, compared to primary school students and college/university students. Half of the studies in Chapter 5 were conducted with secondary school students.

In short, to gain a thorough understanding of what works and why, a model on the effectiveness of feedback for enhancing reading comprehension should be developed that includes both the instructional contexts of feedback (support reading comprehension 'on the job' vs. teaching reading comprehension skills 'off the job') and different design features of feedback (e.g., richness of feedback, timing of feedback). A third valuable component of such a model could be student characteristics that may interact with instructional contexts and design features. Such a model could guide the development of tools for reading comprehension instruction and reading comprehension support.

Conclusions

In conclusion, in this dissertation a methodologically diverse approach was employed to examine internal and external factors that affect reading comprehension and processes underlying reading comprehension. With regard to internal factors, the results first demonstrated the importance of attentional control during reading (i.e., state attentional control) for reading comprehension, particularly when reading a complex text. Second, the results demonstrated that frontal TBR during reading could be used as a potential biophysiological indicator of attentional control during reading. Finding a reliable indicator that could be used for real-time monitoring of attentional control might advance future research on the relation between attentional control, fluctuations in attentional control and reading comprehension, and the development of instructional tools to monitor and guide attentional control during reading. Third, the results revealed that pharmacologically increasing dopamine levels in the brain did not affect attention during reading as measured by frontal TBR and retrospective self-reports, but negatively influenced reading comprehension. The relation between DA levels, attentional control, and reading comprehension appeared to be complex, necessitating further research.

With regard to external factors, the results first showed that providing students with feedback was effective for promoting reading comprehension. Feedback can alert students to flaws in their understanding (i.e., mental representation) of a text, and help them to correct such flaws. Second, the results demonstrated that, to support reading comprehension in the context of learning from text, feedback can best be provided directly after reading and, at a minimum, includes information about the correctness of an answer. The addition of more elaborate feedback might enhance the effects of feedback. Third, the results showed that feedback positively influenced readers' ability to deploy reading strategies, and these effects transferred to texts where they did not receive feedback. This transfer of reading strategy skills subsequently was found to relate to improved reading comprehension. Fourth, the results showed no evidence that feedback while reading functions as motivational input for students. Future research on the effects of feedback on reading comprehension should focus on explaining the effects of feedback in two settings: (1) the use of feedback to support reading comprehension 'on the job' and (2) the use of feedback as an instructional tool for teaching reading comprehension skills 'off the job'.



Samenvatting (Summary in Dutch)

Een aanzienlijk deel van de studenten in alle lagen van het onderwijs ervaart problemen met begrijpend lezen. Deze studenten zijn tijdens het lezen van een tekst niet in staat om een compleet en coherent mentaal model van een tekst te creëren. Een compleet en coherent mentaal model is nodig om de informatie in de tekst te begrijpen en te kunnen toepassen. In andere woorden, om van teksten te kunnen leren. Onvoldoende vaardigheid in begrijpend lezen is niet alleen een bedreiging voor een succesvolle schoolloopbaan, maar verkleint ook de maatschappelijke kansen die iemand heeft.

Het creëren van een compleet en coherent mentaal model van een tekst is een complexe taak waarbij structurele aspecten (wat lezers weten) en functionele aspecten (wat lezers doen) op een complexe manier samenwerken. Gezien de complexe aard van begrijpend lezen, vereist het ontwikkelen van wetenschappelijke kennis hierover een veelzijdige aanpak die zowel tot uiting komt in de variabelen die worden onderzocht als in de onderzoeksmethoden die worden toegepast. Inzicht in de vaardigheden en processen die een rol spelen bij het begrijpend lezen is van fundamenteel belang om (1) individuele verschillen in begrijpend lezen te begrijpen en (2) effectieve methoden om begrijpend lezen te stimuleren of te remediëren te ontwikkelen. Bij een veelzijdige aanpak in het onderzoek naar begrijpend lezen is aandacht nodig voor factoren in de lezer die leiden tot individuele verschillen tussen lezers als ook voor factoren buiten de lezer, zoals bijvoorbeeld de gebruikte didactiek. Een veelzijdige aanpak wordt ook gekenmerkt door diversiteit in de gekozen onderzoeksmethoden waarbij de opbrengst van de ene methode die van een andere methode kan aanvullen.

Het onderzoek dat in dit proefschrift wordt beschreven kenmerkt zich door deze veelzijdige en methodologisch diverse benadering. In Hoofdstuk 2 en 3 worden interne factoren, ofwel individuele verschillen in begrijpend lezen onderzocht in twee experimentele studies. In Hoofdstuk 2 wordt een experiment beschreven naar aandachtsprocessen tijdens het lezen, gemeten via EEG en self-reports, en in Hoofdstuk 3 wordt een toedieningsstudie beschreven waarin de invloed van dopamine op zowel aandachtscontrole als begrijpend lezen wordt onderzocht. De focus in Hoofdstuk 4 en 5 ligt op externe factoren, ofwel didactische methoden om begrijpend lezen aan te leren of te verbeteren. In deze hoofdstukken worden meta-analyses beschreven naar de effecten van feedback op zowel begrijpend lezen (Hoofstuk 4) als op cognitieve en affectieve processen die gerelateerd zijn aan begrijpend lezen (Hoofstuk 5).

In de volgende alinea's worden de belangrijkste bevindingen van de studies zoals beschreven in Hoofdstuk 2, 3, 4 en 5 samengevat, gevolgd door suggesties voor toekomstig onderzoek en implicaties voor de onderwijspraktijk.

Aandachtscontrole en Begrijpend Lezen

Scholieren en studenten groeien op in een wereld waarin de alsmaar toenemende mogelijkheden en functies van digitale apparaten en online platforms, en de enorme toegankelijkheid ervan, bijna non-stop onze aandacht trekken. Als gevolg hiervan wordt het focussen van aandacht op langere taken, zoals het lezen van teksten, een steeds grotere uitdaging. De huidige samenleving wordt daarom ook wel omschreven als 'het tijdperk van afleiding' of 'de aandachtseconomie'. Sommige wetenschappers stellen zelfs dat we ons bevinden in 'een aandachtscrisis'. Het weerstaan van alle informatie op die digitale apparaten en platforms die onze aandacht trekt wordt dan ook gezien als een van de meest fundamentele uitdagingen voor het (leren) lezen en begrijpen van teksten.

Voor begrijpend lezen is het van cruciaal belang dat lezers zowel afleiding van buitenaf als van binnenuit, zoals afleidende gedachten, weerstaan. De lezer moet zijn of haar aandacht richten op relevante informatie in de tekst en die informatie koppelen aan relevante voorkennis om een mentale representatie van de tekst te vormen. Het vermogen om de aandacht te richten en afleiding te weerstaan wordt aandachtscontrole genoemd.

Het doel van Hoofdstuk 2 van dit proefschrift was om de invloed van aandachtscontrole tijdens het lezen op tekstbegrip te onderzoeken. Hoewel zelfrapportages om aandachtscontrole te meten veel worden gebruikt in leesonderzoek, heeft het gebruik van zelfrapportages substantiële nadelen. Daarom onderzochten we in dit hoofdstuk naast het gebruik van zelfrapportages de mogelijkheid om aandachtscontrole op een meer objectieve en ecologische valide manier te meten aan de hand van de frontale theta/beta-ratio (TBR), die wordt verkregen uit EEG-data.

De resultaten van Hoofdstuk 2 toonden aan dat frontale TBR als maat voor aandachtscontrole tijdens het lezen gerelateerd was aan de frontale TBR tijdens een rusttoestand en (marginaal significant) aan zelf gerapporteerde aandachtscontrole in het dagelijks leven. Bovendien waren schommelingen in frontale TBR tijdens het lezen gerelateerd aan het aantal zelf gerapporteerde momenten van afleidende gedachten tijdens het lezen. Dit wijst erop dat schommelingen in frontale TBR tijdens het lezen een indicatie zijn van verschillen in aandachtscontrole (momenten van een gebrek aan aandachtscontrole). Concluderend kan gesteld worden dat de resultaten van deze studie een eerste aanzet vormen voor verder onderzoek naar de geschiktheid van frontale TBR als indicator voor aandachtscontrole tijdens het lezen.

Tot slot hebben we in Hoofdstuk 2 onderzocht in welke mate frontale TBR als maat voor aandachtscontrole gebruikt kan worden om het begrip van een tekst te voorspellen. De resultaten toonden aan dat de gemiddelde frontale TBR tijdens het lezen een significante voorspeller is voor het begrip van een complexe tekst (zoals een tekst waarin moeilijke woorden voorkomen). Studenten met een lagere gemiddelde frontale TBR tijdens het lezen, duidend op betere aandachtscontrole, scoorden hoger op begrijpend lezen. Bovendien medieerde de gemiddelde frontale TBR tijdens het lezen de relatie tussen frontale TBR in een rusttoestand en begrijpend lezen. Dit mediatiemodel toont aan dat aandachtscontrole gerelateerd is aan begrijpend lezen *via* de mate van aandachtscontrole tijdens het lezen. De relatie tussen frontale TBR in rusttoestand en het begrip van een eenvoudige tekst werd niet gemedieerd door de mate van aandachtscontrole tijdens het lezen van die eenvoudige tekst.

De Invloed van Dopamine op Aandachtscontrole en Begrijpend Lezen

De studie beschreven in Hoofdstuk 2 had vooral een methodologische focus. In Hoofdstuk 3 kent de studie naar aandachtscontrole en begrijpend lezen een voornamelijk neurobiologische invalshoek. In een *Double-Blind Randomized Controlled Trial* (RCT) werd de invloed van dopamine op aandachtscontrole en begrijpend lezen getest. Van dopamine (DA) is aangetoond dat het een belangrijke rol speelt in aandachtsprocessen en geheugenvorming. Toch heeft onderzoek naar de effecten van verschillen in DA-niveaus op aandachtsprocessen en geheugenvorming nog geen consistente resultaten opgeleverd.

Een theorie die de verschillen in resultaten zou kunnen verklaren is de *omgekeerde U-vormtheorie* (Cools & Robbins, 2004; Gibbs & D'Esposito, 2005). Volgens deze theorie volgt de relatie tussen DA-niveaus in de hersenen en cognitieve prestaties een omgekeerde U-vorm, wat betekent dat zowel te hoge als te lage DA-niveaus het cognitief functioneren kunnen belemmeren. Dit model verklaart positieve effecten van een farmacologische verhoging van de DA-waarden bij mensen die een te laag DA-niveau in de hersenen hebben, zoals bijvoorbeeld Parkinsonpatiënten. Toch verklaart het niet waarom er ook bij gezonde mensen, waarbij men uitgaat van een in zekere mate optimaal DA-niveau in de hersenen, positieve effecten op leerprestaties worden gevonden na het farmacologisch verhogen van DA-waarden in de hersenen. Om meer inzicht te verkrijgen in de werking van dit mechanisme is een directe test voor de omgekeerde U-vormtheorie nodig.

Om de omgekeerde U-vormtheorie direct te testen, werd een gerandomiseerd placebo-gecontroleerd experiment uitgevoerd waarin de effecten van toediening van levodopa, een voorloper van DA in de hersenen, op aandachtscontrole en begrijpend lezen werden onderzocht. Dit onderzoek werd uitgevoerd met twee groepen studenten: een groep studenten die drager zijn van het DRD4 7-repeat allel (DRD4 7+) en een groep studenten die geen drager zijn van het DRD4 7-repeat allel (DRD4 7-). Het DRD4 7-repeat allel is gerelateerd aan een minder efficiënte transmissie van DA in de hersenen, wat resulteert in lagere DA-niveaus. Van de groep studenten die drager is van dit allel (DRD4 7+) werd daarom verwacht dat ze lagere niveaus van DA in de hersenen hebben en van de groep die geen drager is (DRD4 7-) dat ze meer optimale niveaus van DA hebben. In overeenstemming met de omgekeerde U-vormtheorie verwachtten we een interactie-effect van DRD4-genotype en conditie (levodopa of placebo) op cognitieve prestaties. Ten eerste hebben we de effecten van toediening van levodopa op aandachtscontrole tijdens het lezen getest. We gebruikten daarvoor de EEG-maat (frontale TBR tijdens het lezen) die was onderzocht in de studie in Hoofdstuk 2, en een retrospectieve zelfrapportage van aandachtscontrole die direct na het lezen van een tekst werd ingevuld. Ten tweede onderzochten we de effecten van het toedienen van levodopa op begrijpend lezen.

In tegenstelling tot wat we hadden verwacht, lieten de resultaten geen interactie-effect zien van het DRD4-genotype en de verhoging van de DA-waarden (levodopa vs. placebo) op aandachtscontrole of begrijpend lezen. Dit suggereert dat studenten uit de DRD4 7+ en DRD4 7-groep wat betreft dopaminegehalte gemiddeld niet verschilden in hun positie op de omgekeerde U-vorm. Daarnaast had een verhoging van de DA-waarden geen effect op aandachtscontrole. Dit gold voor elk van de drie gebruikte maten: de gemiddelde frontale TBR tijdens het lezen, fluctuaties in frontale TBR tijdens het lezen en een zelfrapportage van de aandachtscontrole. Verhoogde DA-niveaus hadden wel invloed op begrijpend lezen, maar deze invloed was in beide groepen (DRD4 7- en DRD4 7+) negatief. Dat wil zeggen dat studenten slechter presteerden op begrijpend lezen na toediening van levodopa dan na toediening van een placebo. Deze resultaten zijn niet in overeenstemming met de resultaten die zijn gevonden in eerdere studies, waarin gezonde proefpersonen die levodopa kregen toegediend, nieuwe woorden sneller en beter bleken te leren.

Hoewel het vermogen om teksten aandachtig te lezen en te begrijpen cruciaal is voor succes in het academische, professionele en persoonlijke leven, is het farmacologisch optimaliseren van aandachtscontrole en begrijpend lezen een complexe kwestie. De resultaten van de studie beschreven in Hoofdstuk 3 ondersteunen deze notie van complexiteit. Ten eerste waren studenten die het DRD4 7-repeat allel droegen niet vatbaarder voor de verwachte positieve effecten van toediening van levodopa. Deze discrepantie met wat we hadden verwacht zou erop kunnen wijzen dat andere dopaminereceptorgenen dan het DRD4-receptorgen een crucialere rol spelen bij aandachtscontrole en begrijpend lezen. Ten tweede heeft de hoogopgeleide steekproef (de deelnemers aan de studie waren universiteitsstudenten) er mogelijk toe geleid dat ook binnen de DRD4 7+ groep de dopaminehuishouding relatief gunstig was. Hoewel er geen effecten gevonden werden van verhoogde DA-niveaus in de hersenen op aandachtscontrole tijdens het lezen, was er wel sprake van een negatieve invloed op het begrijpend lezen. Een mogelijke verklaring voor deze ogenschijnlijk tegenstrijdige bevindingen is dat onze maten voor aandachtscontrole wellicht niet sensitief genoeg waren. Een andere mogelijkheid is dat de toediening van levodopa een sterkere invloed heeft op geheugenvorming dan op aandachtscontrole. Ten vierde zijn zowel aandachtscontrole als begrijpend lezen cognitieve processen die een beroep doen op een breed scala aan hersengebieden. Onderzoek heeft aangetoond dat verschillende hersenregio's verschillend vatbaar zijn voor schommelingen in DA-niveaus. Het complexe samenspel tussen de DA-niveaus in verschillende hersenregio's gerelateerd aan aandachtscontrole en begrijpend lezen, zou de resultaten van ons onderzoek kunnen hebben beïnvloed.

Het doel van de studie beschreven in Hoofdstuk 3 was om meer inzicht te krijgen in de neurobiologische processen die ten grondslag liggen aan aandachtscontrole en begrijpend lezen door farmacologisch manipulatie van DA-niveaus in de hersenen. DA-niveaus in de hersenen kunnen ook worden beïnvloed door instructiemethoden zoals het geven van feedback. De studie beschreven in Hoofdstuk 4 was daarom gericht op het effect van feedback op begrijpend lezen.

Het Effect van Feedback op Begrijpend Lezen

In een groot aantal studies is het effect van feedback op leren onderzocht. In deze studies is een grote variatie te zien in de manier waarop feedback is vormgegeven en de manier waarop de feedback aan studenten wordt aangereikt. Als een mogelijk gevolg van deze verscheidenheid zijn de resultaten van deze studies naar het effect van feedback op leren ook wisselend. Daarnaast wordt in bestaande reviewstudies en meta-analyses naar het effect van feedback doorgaans geen onderscheid gemaakt in type leertaak. Dat maakt het moeilijk om op basis van de bestaande literatuur onderbouwde conclusies te trekken over het effect van feedback op specifieke vaardigheden, zoals begrijpend lezen.

Het doel van Hoofdstuk 4 was daarom om aan de hand van een meta-analyse te onderzoeken wat het effect van feedback op begrijpend lezen is. Feedback is daarbij gedefinieerd als individuele informatie die een lezer ontvangt over de mate van zijn of haar begrip van een tekst (bijv. feedback op antwoorden op begripsvragen tijdens of direct na het lezen), met als doel het begrip van een tekst te vergroten. We testten niet alleen het gemiddelde effect van feedback op begrijpend lezen, maar onderzochten ook de effectiviteit van drie ontwerpaspecten van feedback: de timing van de feedback, de hoeveelheid informatie in de feedback en de wijze waarop de lezer de feedback krijgt aangereikt.

Met betrekking tot de timing van de feedback hebben we twee momenten voor het geven van feedback onderscheiden: feedback tijdens het lezen van een tekst en feedback direct na afloop van het lezen van een tekst. Feedback die gegeven wordt tijdens het lezen onderbreekt het leesproces en vereist dat de lezer multitaskt door enerzijds informatie uit de tekst die hij of zij leest te verwerken en anderzijds de informatie in de feedback te verwerken en integreren met de informatie uit de tekst. Onze hypothese was daarom dat het geven van feedback tijdens het lezen een negatief effect zou hebben op het begrip van een tekst, terwijl het geven van feedback na het lezen het begrip zou ondersteunen.

Wat de hoeveelheid informatie in de feedback betreft, vergeleken we drie typen feedback, oplopend in de hoeveelheid informatie in de feedbackboodschap: (1) alleen informatie over de juistheid van het antwoord (goed/fout), (2) het juiste antwoord of (3) uitleg of toelichtingen bij het juiste antwoord (ofwel, uitgebreide feedback). De literatuur over de invloed van de hoeveelheid informatie in de feedback en het effect ervan op begrijpend lezen, is niet eenduidig. Waar sommige studies positieve effecten laten zien als feedback uitgebreider is, laten andere studies geen verband laten zien tussen de hoeveelheid informatie in de feedback en de effecten ervan op begrijpend lezen.

Ten slotte hebben we twee manieren waarop feedback wordt aangeboden getest: computergestuurd en niet-computergestuurd. Al in de loop van de 20e eeuw werd onderzoek gedaan naar de effecten van feedback op leren. Met name de opmars van computerprogramma's voor leesinstructie heeft ervoor gezorgd dat feedback op verschillende manieren aan de lezer kan worden aangereikt (bijv. als geschreven tekst, gesproken tekst of door een visuele tutor op het computerscherm) en op specifiek getimede momenten en plaatsen in een tekst.

De resultaten van de meta-analyse gerapporteerd in Hoofdstuk 4 lieten zien dat feedback een positief effect had op tekstbegrip, maar ook dat de grootte van de effecten in de verschillende studies sterk varieerde. Moderatoranalyses toonden aan dat feedback vooral effectief was wanneer deze direct na het lezen van de tekst werd gegeven en minimaal het juiste antwoord bevatte (alleen het juiste antwoord of uitgebreide feedback). De sterkte van de effecten varieerde van matig tot sterk, wat aangeeft dat feedback die het correcte antwoord bevat en uitgebreide feedback bijzonder effectief zijn voor het ondersteunen van tekstbegrip in vergelijking tot feedback die alleen aangeeft of een respons goed of fout is. Ten slotte bleek computergestuurde feedback gunstiger te zijn voor het ondersteunen van tekstbegrip dan niet-computergestuurde feedback.

De resultaten van de meta-analyse in Hoofdstuk 4 laten zien dat het voor het ontwikkelen of kiezen van (digitale toepassingen voor) instructiestrategieën om tekstbegrip te ondersteunen, het beste is om het leesproces niet te onderbreken en ervoor te zorgen dat feedback minimaal het juiste antwoord bevat, maar bij voorkeur ook aanvullende uitleg of informatie. De informatie kan lezers helpen bij het evalueren en, indien nodig, herzien van hun mentale model van een tekst. Daar kunnen lezers het meest van profiteren als hun werkgeheugen niet wordt overbelast.

Processen die het Effect van Feedback op Begrijpend Lezen Mogelijk Verklaren

Het doel van de in Hoofdstuk 5 beschreven meta-analyses was het begrijpen van de mechanismen die de resultaten uit Hoofdstuk 4 kunnen verklaren. In lijn met de *Feedback Interventie Theorie* (Kluger & DeNisi, 1996) is het niet alleen belangrijk om effecten op de beoogde leeruitkomsten te testen (begrijpend lezen in dit geval), maar ook om de onderliggende cognitieve en affectieve processen die de effecten kunnen verklaren te bestuderen.

Leesstrategieën zijn essentiële cognitieve processen die tijdens het lezen worden toegepast om tot tekstbegrip te komen. Om een tekst te begrijpen, moeten lezers hun tekstbegrip monitoren, vragen stellen, passages herlezen, relaties leggen tussen informatie in verschillende delen van de tekst en achtergrondkennis gebruiken. Om deze cognitieve inspanning te leveren zijn affectieve processen, zoals motivatie, leesattitude en betrokkenheid van belang. Vooral in de onderwijscontext waarin scholieren en studenten verplicht zijn bepaalde teksten te bestuderen en daarvan te leren, wordt een groot beroep gedaan op de affectieve processen. De teksten zijn vaak complex en hebben bovendien een hoge informatiedichtheid. Daarnaast is het niet vanzelfsprekend dat de teksten gaan over onderwerpen die scholieren of studenten interesseren.

Er werden twee meta-analyses uitgevoerd. Eén om het effect van feedback op het gebruik van leesstrategieën te testen en een tweede om het effect van feedback op verschillende motivationele processen die gerelateerd zijn aan begrijpend lezen te testen. Indien een significant effect van feedback op het gebruik van leesstrategieën of motivationele processen werd gevonden, onderzochten we vervolgens of dit effect het effect van feedback op begrijpend lezen kon voorspellen.

De resultaten toonden aan dat feedback een positieve invloed had op het vermogen van lezers om leesstrategieën zelfstandig in te zetten bij het lezen van nieuwe teksten. Deze transfer van kennis en vaardigheden was ook gerelateerd aan het effect van feedback op leesbegrip. Met andere woorden: hoe groter het effect van feedback op het gebruik van leesstrategieën, hoe groter het effect ervan op begrijpend lezen. Feedback had geen effect op motivationele processen. In de studies waarin de effecten van feedback op motivationele processen werden onderzocht, was ook geen sprake van een effect van feedback op begrijpend lezen. Hoewel het aantal studies in de meta-analyses beschreven in

Hoofdstuk 5 beperkt was, bleek het gevonden effect van feedback op het gebruik van leesstrategieën robuust te zijn.

Samengevat tonen de resultaten van de meta-analyses gerapporteerd in Hoofdstuk 5 aan dat feedback een gunstige invloed heeft op de ontwikkeling van cognitieve processen die ten grondslag liggen aan begrijpend lezen, zoals het inzetten van leesstrategieën. Dit effect blijft niet alleen beperkt tot teksten waarbij leerlingen via feedback geholpen worden bij het inzetten van deze strategieën, maar is ook zichtbaar bij teksten die leerlingen zelfstandig en zonder hulp van feedback lezen.

Op basis van de resultaten uit de meta-analyses in Hoofdstuk 5 moeten we ook concluderen dat feedback geen invloed lijkt te hebben op motivationele aspecten. Naast het feit dat motivatie een moeilijk te meten construct is, varieerden de studies in de wijze waarop motivationele processen werden gemeten. Dit zou een verklaring kunnen zijn voor het ontbreken van een effect. Er zijn meer studies nodig om te begrijpen of en, zo ja, hoe feedback en leesmotivatie aan elkaar gerelateerd zijn.

Suggesties voor Toekomstig Onderzoek en Praktische Implicaties

De resultaten van de studies die in dit proefschrift worden beschreven dragen bij aan de literatuur over zowel interne als externe factoren die gerelateerd zijn aan begrijpend lezen.

Aandachtscontrole Meten en Monitoren Tijdens het Lezen

De studie beschreven in Hoofdstuk 2 was een eerste onderzoek naar de relatie tussen aandachtscontrole tijdens het lezen, gemeten aan de hand van de EEG-maat frontale TBR, en begrijpend lezen. Hoewel de studie is uitgevoerd met een kleine steekproef en twee verhalende teksten, waren de effectgroottes overtuigend met het oog op de waarde van frontale TBR als indicator voor aandachtscontrole tijdens het lezen. De gemiddelde frontale TBR tijdens het lezen geeft een indicatie van aandachtscontrole tijdens het lezen en fluctuaties in frontale TBR tijdens het lezen zijn een maat voor schommelingen in de aandachtscontrole van de lezer.

Een nadeel van de gemiddelde frontale TBR tijdens het lezen is dat de meting minder informatief wordt naarmate de lengte van teksten toeneemt. Langere leestaken kunnen tot meer schommelingen in aandachtscontrole leiden waardoor de gemiddelde TBR minder informatief wordt. Hoe de lengte van de tekst en de effectiviteit van de gemiddelde TBR als indicator van aandachtscontrole zich tot elkaar verhouden zou onderwerp moeten zijn van vervolgstudies. Naast variatie in de lengte van teksten is het belangrijk om studies uit te voeren met populaties die verschillen in de mate waarin ze hun aandacht kunnen controleren (bijv. leerlingen met ADHD of leerlingen van verschillende leeftijden).

Technologische ontwikkelingen hebben ertoe geleid dat het inzetten van EEG in onderzoek praktisch steeds haalbaarder is geworden. Zo zijn er nu draagbare en draadloze EEG-headsets, die gekoppeld kunnen worden aan computerprogramma's. Deze zogenaamde *brain-computer interfaces* zouden op termijn mogelijk ingezet kunnen worden in de onderwijspraktijk. Voordat deze stap gezet kan worden is meer onderzoek nodig naar de verschillende EEG-maten die gebruikt kunnen worden om aandachtscontrole tijdens lezen te meten en monitoren. Om die reden voeren we momenteel twee kleinschalige verkennende studies uit om het gebruik van frontale TBR als een real-time indicator van aandachtscontrole tijdens het lezen te onderzoeken.

De ontwikkeling van instructiemethoden om lezers te ondersteunen bij het reguleren van hun aandacht tijdens het lezen zou vooral nuttig kunnen zijn voor groepen leerlingen met aandachtsproblemen, zoals leerlingen met ADHD.

Feedback om Begrijpend Lezen te Faciliteren en Verbeteren

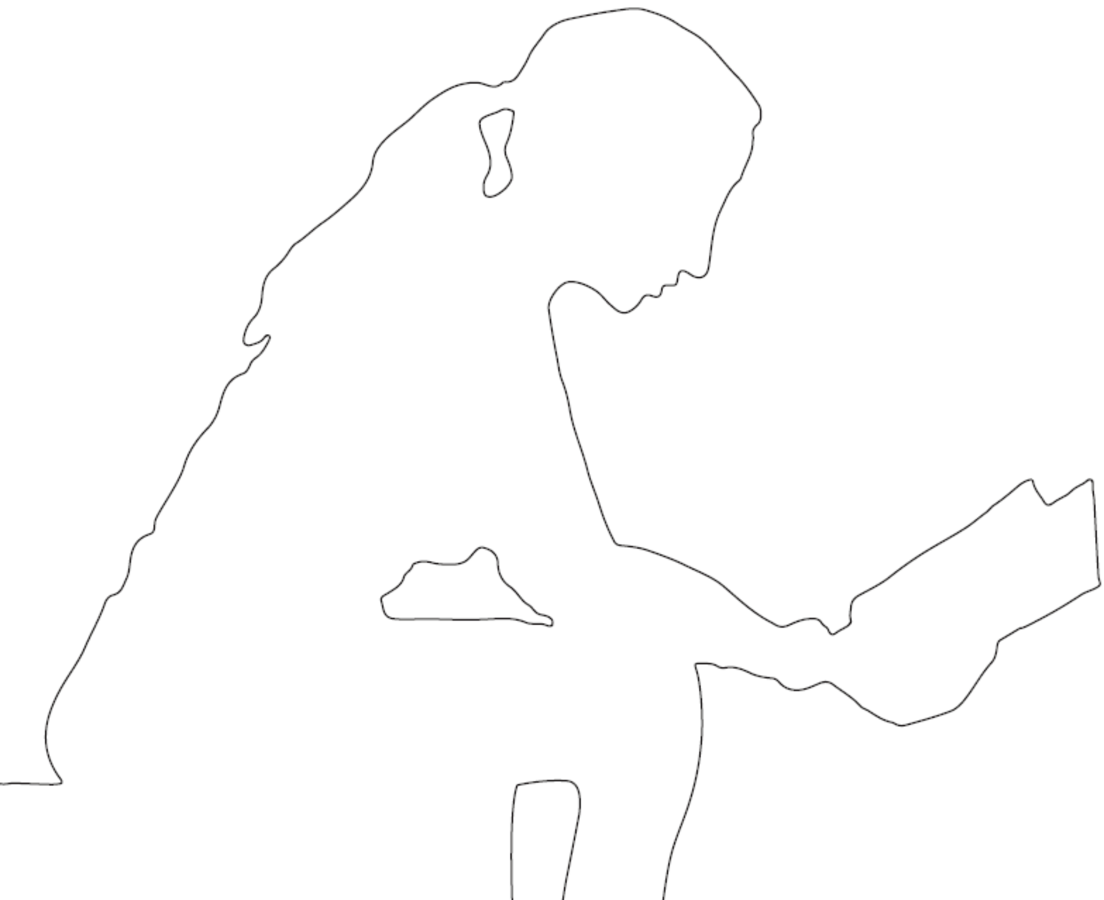
Resultaten van de meta-analyse beschreven in Hoofdstuk 4 toonden aan dat het onderbreken van het lezen voor het geven van feedback een extra belasting vormt voor het werkgeheugen. Het risico is dat het potentieel positieve effect van feedback op begrijpend lezen daardoor teniet wordt gedaan. De resultaten van de meta-analyses beschreven in Hoofdstuk 5 nuanceren dit resultaat. Als feedback gericht is op het aanleren van leesstrategieën blijkt onderbreken van de oefenteksten studenten te helpen het geleerde te oefenen en vervolgens ook toe te passen bij het zelfstandig lezen van nieuwe teksten. De inzet van de leesstrategieën had vervolgens ook een positief effect op leesbegrip. De praktische implicatie hiervan is dat de wijze waarop feedback moet worden vormgegeven (meer of minder uitgebreid) en de timing ervan (tijdens het lezen of erna) afhangt van het beoogde onderwijsdoel. Als feedback bedoeld is om het begrip van de tekst 'on the job' te faciliteren, dan moet feedback het leesproces zo min mogelijk onderbreken. Als feedback bedoeld is om begrijpende leesvaardigheden aan te leren, die ingezet kunnen worden tijdens het lezen van nieuwe teksten, dan kan het leesproces wel onderbroken worden door feedback.

De meerderheid van de studies in Hoofdstuk 5 omvatte feedback die tijdens het lezen werd gegeven. In driekwart van de feedbackstudies naar de relatie tussen het gebruik van leesstrategieën en begrijpend lezen werd gebruik gemaakt van uitgebreide feedback. Daarentegen werd, op één uitzondering na, in alle feedbackstudies naar de relatie tussen motivationele aspecten en begrijpend lezen feedback toegepast die alleen informatie over goed/fout bevatte of het juiste antwoord. Deze typen feedback zijn voor studenten minder informatief en kunnen daardoor minder nuttig zijn bij het corrigeren van inadequate mentale representaties van een tekst. De vraag die nog onbeantwoord blijft is of uitgebreide feedback wel gerelateerd is aan motivationele aspecten bij lezen. Andere factoren die onderbelicht zijn gebleven hebben betrekking op de leeftijd en het leesniveau van leerlingen. Analyses in Hoofdstuk 4 toonden aan dat middelbare scholieren het minst profiteren van feedback in vergelijking tot basisschoolleerlingen en studenten, maar het aantal studies met leerlingen in de basisschoolleeftijd was beperkt.

Conclusie

In dit proefschrift werd een veelzijdige en methodologisch diverse benadering toegepast om interne en externe factoren te onderzoeken die van invloed zijn op begrijpend lezen. De experimentele studie in Hoofdstuk 2 toonde de waarde van frontale TBR als indicator voor het meten en monitoren van aandachtscontrole tijdens het lezen. Daarnaast is aan de hand van de toedieningsstudie in Hoofdstuk 3 verder onderzocht welke rol dopamine speelt bij aandachtscontrole en begrijpend lezen. Uit deze studie bleek dat farmacologisch verhoogde dopaminewaarden de aandacht tijdens het lezen niet beïnvloeden (zoals gemeten door frontale TBR en retrospectieve zelfrapportages), maar wel een negatief effect hebben op begrijpend lezen. Beide studies vergroten daarmee de bestaande kennis over de processen die onderliggend zijn aan begrijpend lezen. Echter, replicaties van deze studies met andere teksten en in andere populaties zijn van belang om de gevonden relaties te bevestigen.

Naast de experimentele studies gericht op interne factoren, laten de meta-analyses in Hoofdstuk 4 en 5 het belang zien van een systematische synthese van een variatie aan studies om zo meer inzicht te krijgen in de werking van feedback en de effecten ervan op begrijpend lezen. De meta-analyse in Hoofdstuk 4 toonde aan dat feedback het begrip van een tekst kan faciliteren, maar dat het daarvoor van belang is dat het leesproces zo min mogelijk wordt onderbroken en dat feedback minimaal informatie moet bevatten over het juiste antwoord op een vraag. De meta-analyses in Hoofdstuk 5 toonden aan dat het onderbreken van het leesproces met feedback ook een didactische doel kan hebben. In deze meta-analyses werd aangetoond dat feedback tijdens het lezen effectief kan zijn om het gebruik leesstrategieën te bevorderen. Deze kennis en vaardigheden werden vervolgens toegepast tijdens het lezen van teksten, waarbij geen feedback werd gegeven. In vervolgonderzoek naar het effect van verschillende ontwerpaspecten van feedback zouden deze twee verschillende onderwijsdoelen, het faciliteren van tekstbegrip en het aanleren van begrijpende leesvaardigheden daarom steeds moeten worden onderscheiden.



References

A

Aarnoutse, C. A. J., & Konings, H. (2013). *Leesattitudeschaal* [Reading Attitude Scale].

Adams, R. H., & Strickland, J. (2012). The effects of computer-assisted feedback strategies in technology education: A comparison of learning outcomes. *Journal of Educational Technology Systems, 40*, 211-223. doi:10.2190/ET.40.2.i

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. E. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron, 50*, 507-517. doi:10.1016/j.neuron.2006.03.036

Afflerbach, P., Hurt, M., & Cho, B. Y. (2020). Reading comprehension strategy instruction. In D. L. Dinsmore, L. K. Fryer, & M. M. Parkinson (Eds.) *Handbook of strategies and strategic processing* (pp. 99-118). Routledge.

Aldemir, R., Demirci, E., Per, H., Canpolat, M., Özmen, S., & Tokmakçı, M. (2018). Investigation of attention deficit hyperactivity disorder (ADHD) sub-types in children via EEG frequency domain analysis. *International Journal of Neuroscience*, *128*(4), 349-360. doi:10.1080/00207454.2017.1382493

Alessandri, G., Zuffianò, A., Vecchione, M., Donnellan, B. M., & Tisak, J. (2016). Evaluating the temporal structure and correlates of daily self-esteem using a trait state error framework (TSE). *Self and Identity*, *15*(4), 394-412. doi:10.1080/15298868.2015.1137223

Alexander, P. A. (2020). What research has revealed about readers' struggles with comprehension in the digital age: Moving beyond the phonics versus whole language debate. *Reading Research Quarterly*, *55* (S1), S89-S97. doi:10.1002/rrq.331

Anderson, R. C., Kulhavy, R. W., & Andre, T. (1972). Conditions under which feedback facilitates learning from programmed lessons. *Journal of Educational Psychology, 63*, 186-188. doi:10.1037/h0032653

Andrianatos, K. (2019). Barriers to reading in higher education: Rethinking reading support. *Reading & Writing*, *10*(1), 1-9. doi:10.4102/rw.v10i1.241

Angelidis, A., van der Does, W., Schakel, L., & Putman, P. (2016). Frontal EEG theta/beta ratio as an electrophysiological marker for attentional control and its test-retest reliability. *Biological Psychology, 121, Part A*, 49-52. doi:10.1016/j.biopsycho.2016.09.008

Ariza, M., Garolera, M., Jurado, M. A., Garcia-Garcia, I., Hernan, I., Sanchez-Garre, C., Vernet-Vernet, M., Sender-Palacios, M. J., Marques-Itturia, I., Pueyo, R., Segura, B., & Narberhaus, A. (2012). Dopamine genes (DRD2/ANKK1-TaqA1 and DRD4-7R) and executive function: Their interaction with obesity. *PloS ONE*, *7*(7), e41482. doi:10.1371/journal.pone.0041482

Arns, M., Conners, C. K., & Kraemer, H. C. (2013). A Decade of EEG theta/beta ratio research in ADHD: A Meta-analysis. *Journal of Attention Disorders, 17*(5), 374-383. doi:10.1177%2F1087054712460087

Arrington, C. N., Kulesz, P. A., Francis, D. J., Fletcher, J. M., & Barnes, M. A. (2014). The contribution of attentional control and working memory to reading comprehension and decoding. *Scientific Studies of Reading, 18*(5), 325-346. doi:10.1080/10888438.2014.902461

Azevedo, R., & Bernard, R. M. (1995). A meta-analysis of the effects of feedback in computer-based instruction. *Journal of Educational Computing Research*, *13*, 111-127. doi:10.2190%2F9LMD-3U28-3A0G-FTQT

B

Baker, L. & Brown, A. L. (1984). Metacognitive skills and reading. In P. D. Pearson, R. Barr, M. L. Kamil, & P. Mosenthal (Eds.) *Handbook of reading research* (pp. 353-393). Lawrence Erlbaum Associates.

Bangert-Drowns, R. L., Kulik, C. L. C., Kulik, J. A., & Morgan, M. (1991). The instructional effect of feedback in test-like events. *Review of Educational Research*, *61*, 213-238. doi:10.3102%2F00346543061002213

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173-1182. doi:10.1037/0022-3514.51.6.1173

Barrett, L. F., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin*, *130*(4), 553-573. doi:10.1037%2F0033-2909.130.4.553

Barry, R. J., Clarke, A. R., & Johnstone, S. J. (2003). A review of electrophysiology in attention-deficit/hyperactivity disorder: I. Qualitative and quantitative electroencephalography. *Clinical Neurophysiology, 114*(2), 171-183. doi:10.1016/S1388-2457(02)00362-0

Bazanova, O. M., & Vernon, D. (2014). Interpreting EEG alpha activity. *Neuroscience & Biobehavioral Reviews*, *44*, 94-110. doi:10.1016/j.neubiorev.2013.05.007

Belísio, A. S., Kolodiuk, F. F., Louzada, F. M., Valdez, P., & Azevedo, C. V. M. (2017). Sleep–wake cycle, daytime sleepiness, and attention components in children attending preschool in the morning and afternoon shifts. *Mind, Brain, and Education, 11*(1), 10-20. doi:10.1111/mbe.12132

Bergeron, P. J., & Rivard, L. (2017). How to engage in pseudoscience with real data: A criticism of John Hattie's arguments in visible learning from the perspective of a statistician. *McGill Journal of Education/Revue des sciences de l'éducation de McGill*, *52*(1), 237-246. doi:10.7202/1040816ar

Berke, J. D. (2018). What does dopamine mean? *Nature Neuroscience*, *21*(6), 787-793. doi:10.1038%2Fs41593-018-0152-y

Bertrams, A., Englert, C., & Dickhäuser, O. (2010). Self-control strength in the relation between trait test anxiety and state anxiety. *Journal of Research in Personality, 44*, 738-741. doi:10.1016/j.jrp.2010.09.005

Bettinger, E., & Long, B. T. (2009). Addressing the needs of underprepared students in higher education: Does college remediation work? *Journal of Human Resources, 44*(3), 736–771. doi:10.3368/jhr.44.3.736

Bonvicini, C., Cortese, S., Maj, C., Baune, B. T., Faraone, S. V., & Scassellati, C. (2020). DRD4 48 bp multiallelic variants as age-population-specific biomarkers in attention-deficit/hyperactivity disorder. *Translational Psychiatry*, *10*(1), 1-19. doi:10.1038/s41398-020-0755-4

Bonvicini, C., Faraone, S. V., & Scassellati, C. (2018). Common and specific genes and peripheral biomarkers in children and adults with attention-deficit/hyperactivity disorder. *The World Journal of Biological Psychiatry*, *19*(2), 80-100. doi:10.1080/15622975.2017.1282175

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2005). *Comprehensive meta-analysis* (Version 2) [Computer Software]. Biostat.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to meta-analysis.* Wiley.

Boulougouris, V., & Tsaltas, E. (2008). Serotonergic and dopaminergic modulation of attentional processes. *Progress in Brain Research*, *172*, 517-542. doi:10.1016/S0079-6123(08)00925-4

Boyer, K. E., Phillips, R., Wallis, M., Vouk, M., & Lester J. (2008). Balancing cognitive and motivational scaffolding in tutorial dialogue. In B. P. Woolf, E. Aïmeur, R. Nkambou, & S. Lajoie (Eds.) *Intelligent Tutoring Systems. ITS 2008. Lecture Notes in Computer Science (vol 5091).* Springer.

Braboszcz, C., & Delorme, A. (2011). Lost in thoughts: Neural markers of low alertness during mind wandering. *NeuroImage, 54*(4), 3040-3047. doi:10.1016/j.neuroimage.2010.10.008

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school (Rev. ed.).* National Academies Press.

Braver, T. S., & Cohen, J. D. (2000). On the control of control: The role of dopamine in regulating prefrontal function and working memory. In S. Monsell & J. Driver, (Eds.). *Control of cognitive processes: Attention and performance XVIII* (pp. 713-737). MIT Press.

Breitenstein, C., Flöel, A., Korsukewitz, C., Wailke, S., Bushuven, S., & Knecht, S. (2006). A shift of paradigm: From noradrenergic to dopaminergic modulation of learning? *Journal of the Neurological Sciences*, *248*(1-2), 42-47. doi:10.1016/j.jns.2006.05.012

Breitenstein, C., Korsukewitz, C., Flöel, A., Kretzschmar, T., Diederich, K., & Knecht, S. (2006). Tonic dopaminergic stimulation impairs associative learning in healthy subjects. *Neuropsychopharmacology*, *31*(11), 2552-2564. doi:10.1038/sj.npp.1301167

Brock, S. E., & Knapp, P. (1996). Reading comprehension abilities of children with attention-deficit/hyperactivity disorder. *Journal of Attention Disorders, 1*(3), 173–185. doi:10.1177/108705479600100305

Burgess, A. (2012). *A Clockwork Orange* (H. Damsma & N. Miedema, Trans.). Athenaeum-Polak & Van Gennep. (Original work published 1962)

Butler, A. C., Godbole, N., & Marsh, E. J. (2013). Explanation feedback is better than correct answer feedback for promoting transfer of learning. *Journal of Educational Psychology, 105*, 290-298. doi:10.1037/a0031026

C

Cain, K. (2010). *Reading Developments and Difficulties.* John Wiley & Sons Ltd.

Calderwood, C., Ackerman, P. L., & Conklin, E. M. (2014). What else do college students "do" while studying? An investigation of multitasking. *Computers & Education, 75*, 19-29. doi:10.1016/j.compedu.2014.02.004

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest, 19*(1), 5-51. doi:10.1177%2F1529100618772271

Cecilia, M. R., Vittorini, P., Cofini, V., & di Orio, F. (2014). The prevalence of reading difficulties among children in scholar age. *Styles of Communication*, *6*(1), 18-30.

Chall, J. S. (1983). *Stages of reading development.* McGraw-Hill

Chang, F. M., Kidd, J. R., Livak, K. J., Pakstis, A. J., & Kidd, K. K. (1996). The world-wide distribution of allele frequencies at the human dopamine D4 receptor locus. *Human Genetics*, *98*(1), 91-101. doi:10.1007/s004390050166

Chen, C. M., & Huang, S. H. (2014). Web-based reading annotation system with an attention-based self-regulated learning mechanism for promoting reading performance. *British Journal of Educational Technology*, *45*(5), 959-980. doi:10.1111/bjet.12119

Chen, N. S., Teng, D. C. E., & Lee, C. H. (2011). Augmenting paper-based reading activity with direct access to digital materials and scaffolded questioning. *Computers & Education, 57*(2), 1705-1715. doi:10.1016/j.compedu.2011.03.013

Chi, M. T. H. (2010). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.) *Advances in instructional psychology: Educational design and cognitive science, Volume 5* (pp. 161-238). Lawrence Erlbaum Associates, Inc.

Chiesa, A., Calati, R., & Serretti, A. (2011). Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings. *Clinical Psychology Review*, *31*(3), 449-464. doi:10.1016/j.cpr.2010.11.003

Christoff, K., Irving, Z. C., Fox, K. C. R., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: a dynamic framework. *Nature Reviews Neuroscience, 17*(11), 718-731. doi:10.1038/nrn.2016.113

Clariana, R. B., & Koul, R. (2006). The effects of different forms of feedback on fuzzy and verbatim memory of science principles. *British Journal of Educational Psychology, 76*, 259-270. doi:10.1348/000709905X39134

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review*, *3*(3), 149-210. doi:10.1007/BF01320076

Coddington, C. S. (2009). *The effects of constructs of motivation that affirm and undermine reading achievement inside and outside of school on middle school students' reading achievement* [Doctoral dissertation, University of Maryland]. Digital Repository of the University of Maryland.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159. doi:10.1037/0033-2909.112.1.155

Conners, F. A. (2009). Attentional control and the simple view of reading. *Reading & Writing, 22,* 591-613. doi:10.1007/s11145-008-9126-x

Cools, R., & D'Esposito, M. (2011). Inverted-U–shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry, 69*(12), 113-125. doi:10.1016/j.biopsych.2011.03.028

Cools, R., & Robbins, T. W. (2004). Chemistry of the adaptive mind. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 362*(1825), 2871-2888. doi:10.1098/rsta.2004.1468

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671-684. doi:10.1016/S0022-5371(72)80001-X

Crawford, M. B. (2015) *The world beyond your head: How to flourish in an age of distraction.* Farrar, Straus and Giruoux.

Crossley, S. A. & McNamara, D. S. (2017). Educational technologies and literacy development. In S. A. Crossley & D. S. McNamara (Eds.), *Adaptive educational technologies for literacy instruction* (pp. 1-12). Routledge.

Craney, T. A., & Surles, J. G. (2002). Model-dependent variance inflation factor cutoff values. *Quality Engineering*, *14*(3), 391-403. doi:10.1081/QEN-120001878

D

Davidson, J., & Noyes, P. (1995). Computer-generated speech-feedback as support for reading instruction. *Support for Learning*, *10*, 35-39. doi:10.1111/j.1467-9604.1995.tb00008.x

Davis, R. O. (2018). The impact of pedagogical agent gesturing in multimedia learning environments: A meta-analysis. *Educational Research Review, 24*, 193-209. doi:10.1016/j.edurev.2018.05.002

Dempsey, J. V., & Wager, S. U. (1988). A taxonomy for the timing of feedback in computer-based instruction. *Educational Technology*, *28*(10), 20-25.

De Naeghel, J., Van Keer, H., Vansteenkiste, M., & Rosseel, Y. (2012). The relation between elementary students' recreational and academic reading motivation, reading frequency, engagement, and comprehension: A self-determination theory perspective. *Journal of Educational Psychology*, *104*(4), 1006-1021. doi:10.1037/a0027800

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111*(2), 225-236. doi:10.1037/0021-843X.111.2.225

De Vries, M. H., Ulte, C., Zwitserlood, P., Szymanski, B., & Knecht, S. (2010). Increasing dopamine levels in the brain improves feedback-based procedural learning in healthy participants: an artificial-grammar-learning experiment. *Neuropsychologia*, *48*(11), 3193-3197. doi:10.1016/j.neuropsychologia.2010.06.024

Diamond, A., Briand, L., Fossella, J., & Gehlbach, L. (2004). Genetic and neurochemical modulation of prefrontal cognitive functions in children. *American Journal of Psychiatry*, *161*(1), 125-132. doi:10.1176/appi.ajp.161.1.125

Dimigen, O., Sommer, W., Hohlfeld, A., Jacobs, A. M., & Kliegl, R. (2011). Coregistration of eye movements and EEG in natural reading: analyses and review. *Journal of Experimental Psychology: General*, *140*(4), 552-572. doi:10.1037/a0023885

Dixon, P., & Bortolussi, M. (2013). Construction, integration, and mind wandering in reading. *Canadian Journal of Experimental Psychology, 67*(1), 1-10. doi:10.1037/a0031234

Dole, J. A., Duffy, G. G., Roehler, L. R., & Pearson, P. D. (1991). Moving from the old to the new: Research on reading comprehension instruction. *Review of Educational Research, 61,* 239-264. doi:10.3102%2F00346543061002239

Duke, N., & Pearson, P. (2008). Effective practices for developing reading comprehension. *The Journal of Education, 189*(1/2), 107-122. doi:10.1177%2F0022057409189001-208

Duval, S., & Tweedie, R. (2000). A nonparametric "trim and fill" method for accounting for publication bias in meta-analysis. *Journal of the American Statistical Association, 95*, 89–98. doi:10.1080/01621459.2000.10473905

E

Edossa, A. K., Neuenhaus, N., Artelt, C., Lingel, K., & Schneider, W. (2019). Developmental relationship between declarative metacognitive knowledge and reading comprehension during secondary school. *European Journal of Psychology of Education*, *34*(2), 397-416. doi:10.1007/s10212-018-0393-x

Edmonds, M. S., Vaughn, S., Wexler, J., Reutebuch, C., Cable, A., Tackett, K. K., & Schnakenberg, J. W. (2009). A synthesis of reading interventions and effects on reading comprehension outcomes for older struggling readers. *Review of Educational Research*, *79*, 262-300. doi:10.3102%2F0034654308325998

Ehrlich, M.-F., Remond, M., & Tardieu, H. (1999). Processing of anaphoric devices in young skilled and less skilled comprehenders: Differences in metacognitive monitoring. *Reading and Writing 11*(1), 29-63. doi:10.1023/A:1007996502372

Elleman, A. M., & Compton, D. L. (2017). Beyond comprehension strategy instruction: What's next? *Language, Speech, and Hearing Services in Schools*, *48*(2), 84-91. doi:10.1044/2017_LSHSS-16-0036

F

Faber, M., Bixler, R., & D'Mello, S. K. (2018). An automated behavioral measure of mind wandering during computerized reading. *Behavior Research Methods, 50*(1), 134-150. doi:10.3758/s13428-017-0857-y

Faber, M., & D'Mello, S. K. (2018). How the stimulus influences mind wandering in semantically rich task contexts. *Cognitive Research: Principles and Implications, 3*(1), 35. doi:10.1186/s41235-018-0129-0

Fan, J., Wu, Y., Fossella, J. A., & Posner, M. I. (2001). Assessing the heritability of attentional networks. *BMC Neuroscience, 2*(1), 14. doi:10.1186/1471-2202-2-14

Farragher, P., & Yore, L. D. (1997). The effects of embedded monitoring and regulating devices on the achievement of high school students learning science from text. *School Science and Mathematics, 97*(2), 87-95. doi:10.1111/j.1949-8594.1997.tb17348.x

Feldhusen, J. F., & Birt, A. (1962). A study of nine methods of presentation of programmed learning material. *The Journal of Educational Research, 55*, 461-466. doi:10.1037/h0030766

Feng, S., D'Mello, S. K., & Graesser, A. (2013). Mind wandering while reading easy and difficult texts. *Psychonomic Bulletin & Review, 20*(3), 586-592. doi:10.3758/s13423-012-0367-y

Field, A. (2013). *Discovering statistics using IBM SPSS statistics.* Sage Publications.

Florax, M., & Ploetzner, R. (2010). What contributes to the split-attention effect? The role of text segmentation, picture labelling, and spatial proximity. *Learning and Instruction*, *20*, 216-224. doi:10.1016/j.learninstruc.2009.02.021

Flory, K., Milich, R., Lorch, E.P., Hayden, A. N., Strange, C., & Welsh, R. (2006). Online story comprehension among children with ADHD: Which core deficits are involved? *Journal of Abnormal Child Psychology, 34,* 850–862. doi:10.1007/s10802-006-9070-7

Fong, C. J., Patall, E. A., Vasquez, A. C., & Stautberg, S. (2019). A Meta-analysis of negative feedback on intrinsic motivation. *Educational Psychology Review, 31*, 121-162. doi:10.1007/s10648-018-9446-6

Forrin, N. D., Risko, E. F., & Smilek, D. (2017). On the relation between reading difficulty and mind-wandering: a section-length account. *Psychological Research*, 1-13. doi:10.1007/s00426-017-0936-9

Fortenbaugh, F. C., DeGutis, J., & Esterman, M. (2017). Recent theoretical, neural, and clinical advances in sustained attention research. *Annals of the New York Academy of Sciences*, *1396*(1), 70-91. doi:10.1111%2Fnyas.13318

Fragkos, K. C., Tsagris, M., & Frangos, C. C. (2014). Publication bias in meta-analysis: confidence intervals for Rosenthal's fail-safe number. *International Scholarly Research Notices, 2014,* 1-17. doi:10.1155/2014/825383

Fuchs, D. & Fuchs, L. S. (2005). Peer Assisted Learning Strategies: Promoting word recognition, fluency and reading comprehension in young children. *The Journal of Special Education, 39*(1), 34-44. doi:10.1177%2F0022466905039001040

Furedi, F. (2016, February 25). *The crisis of attention: It's not smartphones and Facebook that are making us permanently distracted.* Spiked. https://www.spiked-online.com/2016/02/25/the-crisis-of-attention/

G

Gambrell, L. B., Palmer, B. M., Codling, R. M., & Mazzoni, S. A. (1996). Assessing motivation to read. *Reading Teacher*, *49*(7), 518-533. doi:10.1598/RT.49.7.2

Gazzaley, A., & Rosen, L. D. (2016). *The distracted mind: Ancient brains in a high-tech world.* The MIT Press.

George, J. M. (1991). State or trait: Effects of positive mood on prosocial behaviors at work. *Journal of Applied Psychology*, *76*(2), 299-307. doi:10.1037/0021-9010.76.2.299

Georgiou, G. K., & Das, J. P. (2016). Direct and indirect effects of executive function on reading comprehension in young adults. *Journal of Research in Reading*, *41*, 243-258. doi:10.1111/1467-9817.12091

Gersten, R., Fuchs, L. S., Williams, J. P., & Baker, S. (2001). Teaching reading comprehension strategies to students with learning disabilities: A review of research. *Review of Educational Research*, *71*(2), 279-320. doi:10.3102%2F00346543071002279

Gibbs, S. E. B., & D'Esposito, M. (2005). A functional MRI study of the effects of bromocriptine, a dopamine receptor agonist, on component processes of working memory. *Psychopharmacology, 180*(4), 1-10. doi:10.1007/s00213-005-0077-5

Golchert, J., Smallwood, J., Jefferies, E., Seli, P., Huntenburg, J. M., Liem, F., Lauckner, M. E., Oligschläger, S., Bernhardt, B. C., Villringer, A., & Margulies, D.S. (2017). Individual variation in intentionality in the mind-wandering state is reflected in the integration of the default-mode, fronto-parietal, and limbic networks. *NeuroImage*, *146*, 226-235. doi:10.1016/j.neuroimage.2016.11.025

Golke, S., Dörfler, T., & Artelt, C. (2015). The impact of elaborated feedback on text comprehension within a computer-based assessment. *Learning and Instruction, 39*, 123-136. doi:10.1016/j.learninstruc.2015.05.009

González-Burgos, I., & Feria-Velasco, A. (2008). Serotonin/dopamine interaction in memory formation. *Progress in Brain Research, 172*, 603-623. doi:10.1016/S0079-6123(08)00928-X

Gorzycki, M., Howard, P., Allen, D., Desa, G., & Rosegard, E. (2016). An exploration of academic reading proficiency at the university level: A cross-sectional study of 848 undergraduates. *Literacy Research and Instruction*, *55*(2), 142-162. doi:10.1080/19388071.2015.1133738

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education*, *7*(1), 6-10. doi:10.1177%2F074193258600700104

Graesser, A. C. (2007). An introduction to strategic reading comprehension. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies* (pp. 3-26). Lawrence Erlbaum Associates.

Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. *Annual Review of Psychology*, *48*, 163-189. doi:10.1146/annurev.psych.48.1.163

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, *101*(3), 371-395. doi:10.1037/0033-295X.101.3.371

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55*(4), 468-484. doi:10.1016/0013-4694(83)90135-9

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. *Current Biology*, *22*(6), R197-R206. doi:10.1016/j.cub.2012.02.012

Grossman, M., Glosser, G., Kalmanson, J., Morris, J., Stern, M. B., & Hurtig, H. I. (2001). Dopamine supports sentence comprehension in Parkinson's Disease. *Journal of the Neurological Sciences, 184*(2), 123-130. doi:10.1016/S0022-510X(00)00491-3

Guthrie, J. T., & Wigfield, A. (2000). Engagement and motivation in reading. In M. L. Kamil (Ed.), *Handbook of reading research* (Vol. 3, pp. 403–418). Erlbaum Associates.

Guthrie, J. T., Wigfield, A., & You, W. (2012). Instructional contexts for engagement and achievement in reading. In S. Christensen, A. Reschly, & C. Wylie (Eds.) *Handbook of research on student engagement* (pp. 601-634). Springer. doi:10.1007/978-1-4614-2018-7_29

H

Hamid, A. A., Pettibone, J. R., Mabrouk, O. S., Hetrick, V. L., Schmidt, R., Vander Weele, C. M., Kennedy, R. T., Aragona, B. J., & Berke, J. D. (2016). Mesolimbic dopamine signals the value of work. *Nature Neuroscience*, *19*(1), 117-126. doi:10.1038/nn.4173

Hampel, F. R., Ronchetti, E. M., Rousseeuw, P. J., & Stahel, W. A. (1986). *Robust statistics: The approach based on influence functions*. Wiley.

Hattie, J. (2012). *Visible learning for teachers: Maximizing impact on learning.* Routledge.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*, 81-112. doi:10.3102%2F003465430298487

Hjetland, H. N., Brinchmann, E. I., Scherer, R., Hulme, C., & Melby-Lervåg, M. (2020). Preschool pathways to reading comprehension: A systematic meta-analytic review. *Educational Research Review*, *30*, 100323. doi:10.1016/j.edurev.2020.100323

Hoffman, J. V. (2017). Comprehension is *not* simple: Considering the persisting dangers in the simple view of reading comprehension. In S. E. Israel (Ed.) *Handbook of research on reading comprehension* (pp. 57-69). The Guilford Press.

Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*(4), 679-709. doi:10.1037/0033-295X.109.4.679

Hoska, D. M. (1993). Motivating learners through CBI feedback: Developing a positive learner perspective. In J. V. Demspey & G. C. Sales (Eds.) *Interactive instruction and feedback* (pp. 105-132). Educational Technology Publications.

I

Ilies, R., Judge, T. A., & Wagner, D. T. (2010). The influence of cognitive and affective reactions to feedback on subsequent goals. *European Psychologist*, *15*, 121-131. doi:10.1027/1016-9040/a000011

Israel, S. E. (2017). Sophistication of reading comprehension: Where to from here? In S. E. Israel (Ed.) *Handbook of research on reading comprehension* (pp. 649-657). The Guilford Press.

Israel, S. E. & Reutzel, D. R. (2017). The consequential pulse of reading comprehension research. In S. E. Israel (Ed.) *Handbook of research on reading comprehension* (pp. 57-69). The Guilford Press.

J

Jacobs, P. I., & Kulkarni, S. (1963). A test of some assumptions underlying programed instruction. *Psychological Reports, 18,* 103-110. doi:10.1002/j.2333-8504.1963.tb00495.x

Jacobs, J. E., Lanza, S., Osgood, D. W., Eccles, J. S., & Wigfield, A. (2002). Changes in children's self-competence and values: Gender and domain differences across grades one through twelve. *Child Development*, *73*(2), 509-527. doi:10.1111/1467-8624.00421

Jaehnig, W., & Miller, M. L. (2007). Feedback types in programmed instruction: A systematic review. *The Psychological Record*, *57*, 219-232. doi:10.1007/BF03395573

Joensson, M., Thomsen, K. R., Andersen, L. M., Gross, J., Mouridsen, K., Sandberg, K., Østergaard, L., & Lou, H. C. (2015). Making sense: dopamine activates conscious self-monitoring through medial prefrontal cortex. *Human Brain Mapping*, *36*(5), 1866-1877. doi:10.1002/hbm.22742

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: a review of our current understanding. *Neuropsychology Review*, *17*, 213-233. doi:10.1007/s11065-007-9040-z

K

Kähkönen, S., Ahveninen, J., Pekkonen, E., Kaakkola, S., Huttunen, J., Ilmoniemi, R. J., & Jääskeläinen, I. P. (2002). Dopamine modulates involuntary attention shifting and reorienting: an electromagnetic study. *Clinical Neurophysiology*, *113*(12), 1894-1902. doi:10.1016/S1388-2457(02)00305-X

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: a meta-analysis of executive-control and working memory training in older adults. *Psychological Science*, *25*(11), 2027–2037. doi:10.1177/0956797614548725

Kealy, W. A. & Ritzhaupt, A. D. (2010). Assessment certitude as a feedback strategy for learners' constructed responses. *Journal of Educational Computing Research*, *43*, 25-45. doi:10.2190%2FEC.43.1.c

Kendeou, P., van den, Broek, P., Helder, A. and Karlsson, J. (2014), A cognitive view of reading comprehension: Implications for reading difficulties. *Learning Disabilities Research & Practice, 29,* 10-16. doi:10.1111/ldrp.12025

Kerr, M. M., & Frese, K. M. (2017). Reading to learn or learning to read? Engaging college students in course readings. *College Teaching*, *65*(1), 28-31. doi:10.1080/87567555.2016.1222577

Kieffer, M. J., Vukovic, R. K., & Berry, D. (2013). Roles of attention shifting and inhibitory control in fourth-grade reading comprehension. *Reading Research Quarterly*, *48*(4), 333-348. doi:10.1002/rrq.54

Kintsch, W. (1986). Learning from text. *Cognition and Instruction*, *3*(2), 87-108. doi:10.1207/s1532690xci0302_1

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*, 163-182. doi:10.1037/0033-295X.95.2.163

Kischka, U., Kammer, T. H., Maier, S., Weisbrod, M., Thimm, M., & Spitzer, M. (1996). Dopaminergic modulation of semantic network activation. *Neuropsychologia, 34*(11), 1107-1113. doi:10.1016/0028-3932(96)00024-3

Kjaer, T. W., Bertelsen, C., Piccini, P., Brooks, D., Alving, J., & Lou, H. C. (2002). Increased dopamine tone during meditation-induced change of consciousness. *Cognitive Brain Research*, *13*(2), 255-259. doi:10.1016/S0926-6410(01)00106-9

Klauda, S. L., & Guthrie, J. T. (2015). Comparing relations of motivation, engagement, and achievement among struggling and advanced adolescent readers. *Reading and Writing*, *28*(2), 239-269. doi:10.1007/s11145-014-9523-2

Klein, T. A., Neumann, J., Reuter, M., Hennig, J., von Cramon, D. Y., & Ullsperger, M. (2007). Genetically determined differences in learning from errors. *Science*, *318*(5856), 1642-1645. doi:10.1126/science.1145044

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, *16*(12), 606-617. doi:10.1016/j.tics.2012.10.007

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Research Reviews*, *53*(1), 63-88. doi:10.1016/j.brainresrev.2006.06.003

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin*, *119*, 254-284. doi:10.1037/0033-2909.119.2.254

Knecht, S., Breitenstein, C., Bushuven, S., Wailke, S., Kamping, S., Flöel, A., Zwitserlood, P. & Ringelstein, E. B. (2004). Levodopa: faster and better word learning in normal humans. *Annals of Neurology*, *56*(1), 20-26. doi:10.1002/ana.20125

Ko, J. H., Ptito, A., Monchi, O., Cho, S. S., Van Eimeren, T., Pellecchia, G., Ballanger, B., Rusjan, P., Houle, S., & Strafella, A. P. (2009). Increased dopamine release in the right anterior cingulate cortex during the performance of a sorting task: a [11C] FLB 457 PET study. *Neuroimage*, *46*(2), 516-521. doi:10.1016%2Fj.neuroimage.2009.02.031

Konishi, M., Brown, K., Battaglini, L., & Smallwood, J. (2017). When attention wanders: Pupillometric signatures of fluctuations in external attention. *Cognition*, *168*, 16-26. doi:10.1016/j.cognition.2017.06.006

Krimsky, M., Forster, D. E., Llabre, M. M., & Jha, A. P. (2017). The influence of time on task on mind wandering and visual working memory. *Cognition*, *169*, 84-90. doi:10.1016/j.cognition.2017.08.006

Kulhavy, R. W. (1977). Feedback in written instruction. *Review of Educational Research*, *47*, 211-232. doi:10.3102%2F00346543047002211

Kulhavy, R. W., & Stock, W. A. (1989). Feedback in written instruction: The place of response certitude. *Educational Psychology Review*, *1*, 279-308. doi:10.1007/BF01320096

Kulhavy, R. W. & Wager, W. (1993). Feedback in programmed instruction: Historical context and implications for practice. In J. V. Demspey & G. C. Sales (Eds.) *Interactive instruction and feedback* (pp. 3-20). Educational Technology Publications.

L

Lancaster, G. A., Dodd, S., & Williamson, P. R. (2004). Design and analysis of pilot studies: recommendations for good practice. *Journal of Evaluation in Clinical Practice*, *10*(2), 307-312. doi:10.1111/j..2002.384.doc.x

LaRusso, M., Kim, H. Y., Selman, R., Uccelli, P., Dawson, T., Jones, S., Donovan, S., & Snow, C. (2016). Contributions of academic language, perspective taking, and complex reasoning to deep reading comprehension. *Journal of Research on Educational Effectiveness, 9*(2), 201-222. doi:10.1080/19345747.2015.1116035

Lasoff, E. M. (1981). *The effects of feedback in both computer-assisted instruction and programmed instruction on achievement and attitude* (Publication No. 8121115) [Doctoral dissertation, University of Miami]. ProQuest Dissertations and Theses Global.

Lee, H. W., Lim, K. Y., & Grabowski, B. L. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development, 58*, 629-648. doi:10.1007/s11423-010-9153-6

Linssen, A. M. W., Sambeth, A., Vuurman, E. F. P. M., & Riedel, W. J. (2014). Cognitive effects of methylphenidate and levodopa in healthy volunteers. *European Neuropsychopharmacology*, *24*(2), 200-206. doi:10.1016/j.euroneuro.2013.09.009

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis.* Sage.

Llorens, A. C., Cerdán, R., & Vidal-Abarca, E. (2014). Adaptive formative feedback to improve strategic search decisions in task-oriented reading. *Journal of Computer Assisted Learning, 30,* 233-251. doi:10.1111/jcal.12050

Llorens, A. C., Vidal-Abarca, E., & Cerdán, R. (2016). Formative feedback to transfer self-regulation of task-oriented reading strategies. *Journal of Computer Assisted Learning, 32*, 314-331. doi:10.1111/jcal.12134

Locke, E. A., & Latham, G. P. (1990). *A theory of goal setting & task performance*. Prentice-Hall, Inc.

M

MacGregor, S. K. (1988). Use of self-questioning with a computer-mediated text system and measures of reading performance. *Journal of Reading Behavior*, *20*, 131-148. doi:10.1080%2F10862968809547631

Máñez, I., Vidal-Abarca, E., Kendeou, P., & Martínez, T. (2019). How do students process complex formative feedback in question-answering tasks? A think-aloud study. *Metacognition and Learning*, *14*(1), 65-87. doi:10.1007/s11409-019-09192-w

Martin, F., Klein, J. D., & Sullivan, H. (2007). The impact of instructional elements in computer-based instruction. *British Journal of Educational Technology, 38*, 623-636. doi:10.1111/j.1467-8535.2006.00670.x

Maxwell, S. E. (2004). The persistence of underpowered studies in psychological research: Causes, consequences, and remedies. *Psychological Methods, 9*(2), 147-163. doi:10.1037/1082-989X.9.2.147

Mayer, R. E. (1996). Learners as information processors: Legacies and limitations of educational psychology's second. *Educational Psychologist*, *31*(3-4), 151-161. doi:10.1080/00461520.1996.9653263

McNamara, D. S., & Kendeou, P. (2011). Translating advances in reading comprehension research to educational practice. *International Electronic Journal of Elementary Education*, *4*(1), 33-46.

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin, 136*(2), 188-197. doi:10.1037/a0018298

McVay, J.C., & Kane, M.J. (2012). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General, 141*(2), 302-320. doi:10.1037/a0025250

Melara, R. D. (2004) The cognitive neuroscience of attention. In A. Johnson & R. W. Proctor (Eds.). *Attention: Theory and practice* (pp. 333-365). Sage Publications.

Merkelbach, I. (2018). *Protective teaching mechanisms in case of mild perinatal adversity* (Doctoral dissertation). Leiden University.

Metcalfe, J., Kornell, N., & Finn, B. (2009). Delayed versus immediate feedback in children's and adults' vocabulary learning. *Memory & Cognition*, *37*, 1077-1087. doi:10.3758/MC.37.8.107

Mikulecky, L. (1987, December 4). *The effectiveness of interactive computer assisted modelling in teaching study strategies and concept mapping of college textbook material* [Paper presentation]. National Reading Conference, St. Petersburg Beach, FL, United States.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167-202. doi:10.1146/annurev.neuro.24.1.167

Miller, M., Nevado-Montenegro, A. J., & Hinshaw, S. P. (2012). Childhood executive function continues to predict outcomes in young adult females with and without childhood-diagnosed ADHD. *Journal of Abnormal Child Psychology*, *40*(5), 657-668. doi:10.1007/s10802-011-9599-y

Mol, S. E., Bus, A. G., & De Jong, M. T. (2009). Interactive book reading in early education: A tool to stimulate print knowledge as well as oral language. *Review of Educational Research*, *79*, 979-1007. doi:10.3102%2F0034654309332561

Mol, S. E., Bus, A. G., De Jong, M. T., & Smeets, D. J. H. (2008). Added value of parent-child dialogic book readings: A meta-analysis. *Early Education and Development, 19,* 7–26. doi:10.1080/10409280701838603

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*, 358-368. doi:10.1037/0022-0663.91.2.358

Mory, E. H. (2004). Feedback research revisited. In D. H. Jonassen (Ed.) *Handbook of research on educational communications and technology* (2nd edition, pp. 745-783). Lawrence Erlbaum Associates.

Moss, J., Schunn, C. D., Schneider, W., & McNamara, D. S. (2013). The nature of mind wandering during reading varies with the cognitive control demands of the reading strategy. *Brain Research, 1539*, 48-60. doi:10.1016/j.brainres.2013.09.047

Moustafa, A. A., Herzallah, M. M., & Gluck, M. A. (2013). Dissociating the cognitive effects of levodopa versus dopamine agonists in a neurocomputational model of learning in Parkinson's disease. *Neurodegenerative Diseases*, *11*(2), 102-111. doi:10.1159/000341999

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness training improves working memory capacity and GRE performance while reducing mind wandering. *Psychological Science*, *24*(5), 776-781. doi:10.1177%2F0956797612459659

Mudde, T. (2019, July 26). *Aandacht graag* [Attention please]. De Volkskrant

Muijselaar, M. M. L., Swart, N. M., Steenbeek-Planting, E. G., Droop, M., Verhoeven, L., & de Jong, P. F. (2017) Developmental relations between reading comprehension and reading strategies. *Scientific Studies of Reading, 21,* 194-209, doi:10.1080/10888438.2017.1278763

Mullet, H. G., & Marsh, E. J. (2016). Correcting false memories: Errors must be noticed and replaced. *Memory & Cognition*, *44*(3), 403-412. doi:10.3758/s13421-015-0571-x

Munro, C. A., McCaul, M. E., Wong, D. F., Oswald, L. M., Zhou, Y., Brasic, J., Kuwabara, H., Kumar, A., Alexander, M., Ye, W., & Wand, G. S. (2006). Sex differences in striatal dopamine release in healthy adults. *Biological Psychiatry*, *59*(10), 966-974. doi:10.1016/j.biopsych.2006.01.008

N

Nation, P. (2020). The different aspects of vocabulary knowledge. In S. Webb (Ed.) *The Routledge handbook of vocabulary studies* (pp. 15-29). Routledge.

National Reading Panel (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction.* National Institute of Child Health and Human Development.

Neugebauer, S. R. (2013). A daily diary study of reading motivation inside and outside of school: A dynamic approach to motivation to read. *Learning and Individual Differences*, *24*, 152-159. doi:10.1016/j.lindif.2012.10.011

Nielen, T. M. J., Smith, G. G., Sikkema-de Jong, M. T., Drobisz, J., van Horne, B., & Bus, A. G. (2017). Digital guidance for susceptible readers: Effects on fifth graders' reading motivation and incidental vocabulary learning. *Journal of Educational Computing Research*, *56*, 48-73. doi:10.1177%2F0735633117708283

Nieoullin, A. (2002). Dopamine and the regulation of cognition and attention. *Progress in Neurobiology, 67*(1), 53-83. doi:10.1016/S0301-0082(02)00011-4

Nikolaev, A. R., Meghanathan, R. N., & van Leeuwen, C. (2016). Combining EEG and eye movement recording in free viewing: Pitfalls and possibilities. *Brain and Cognition*, *107*, 55-83. doi:10.1016/j.bandc.2016.06.004

Noymer, A. (2011). Alpha, significance level of test. In P. J. Lavrakas (Ed.) *Encyclopedia of survey research methods* (pp. 17-19). Sage Publications. doi:10.4135/9781412963947

O

OECD (2010), *PISA 2009 Results: What students know and can do: Student performance in reading, mathematics and science (Volume I)*. doi:10.1787/9789264091450-en

OECD (2014), *PISA 2012 Results: What students know and can do – Student performance in mathematics, reading and science (Volume I, Revised edition, February 2014).* doi:10.1787/9789264208780-en

OECD (2016). *PISA 2015 Results (Volume I): Excellence and equity in education.* doi:10.1787/9789264266490-en

OECD (2019). *PISA 2018 Results (Volume I): What students know and can do.* doi:10.1787/5f07c754-en

Okkinga, M., van Steensel, R., van Gelderen, A. J., van Schooten, E., Sleegers, P. J., & Arends, L. R. (2018). Effectiveness of reading-strategy interventions in whole classrooms: A meta-analysis. *Educational Psychology Review, 30*, 1215-1239. doi:10.1007/s10648-018-9445-7

Orwin, R. G. (1983). A fail-safe N for effect size in meta-analysis. *Journal of Educational Statistics*, *8*(2), 157-159. doi:10.3102%2F10769986008002157

Ouellette, G., & Beers, A. (2010). A not-so-simple view of reading: How oral vocabulary and visual-word recognition complicate the story. *Reading and Writing*, *23*(2), 189-208. doi:10.1007/s11145-008-9159-1

Owen, A., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., Howard, R. J., & Ballard, C. G. (2010). Putting brain training to the test. *Nature, 465,* 775–778. doi:10.1038/nature09042

P

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science*, *32*, 1-8. doi:10.1023/B:TRUC.0000021806.17516.d0

Pak, S. S., & Weseley, A. J. (2012). The effect of mandatory reading logs on children's motivation to read. *Journal of Research in Education*, *22*(1), 251-265.

Palinscar, A. S. and Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1*(2), 117-175. doi:10.1207/s1532690xci0102_1

Palladino, P., Cornoldi, C., De Beni, R., & Pazzaglia, F. (2001). Working memory and updating processes in reading comprehension. *Memory & Cognition*, *29*(2), 344-354. doi:10.3758/BF03194929

Paris, S. G., & Jacobs, J. E. (1984). The benefits of informed instruction for children's reading awareness and comprehension skills. *Child Development, 55*(6), 2083-2093. doi:10.2307/1129781

Pearson, P. D., Cervetti, G., Invernizzi, M., & Hayes, L. (2012). Should the focus of literacy education be on "reading to learn" or "learning to read"?. In A. J. Eakle, C. J. Russon, & A. G. Osborne Jr. (Eds.), *Curriculum and instruction: Debating issues in American education* (pp. 75-81). Sage Publications

Pedhazur, E. J. *Multiple regression in behavioral research.* Thomson Learning.

Peterson, E. R., & Irving, S. E. (2008). Secondary school students' conceptions of assessment and feedback*. Learning and Instruction, 18*(3), 238-250. doi:10.1016/j.learninstruc.2007.05.001

Peverly, S. T., & Wood, R. (2001). The effects of adjunct questions and feedback on improving the reading comprehension skills of learning-disabled adolescents. *Contemporary Educational Psychology, 26,* 25-43. doi:10.1006/ceps.1999.1025

Putman, P., van Peer, J., Maimari, I., & van der Werff, S. (2010). EEG θ/β-ratio in relation to fear-modulated response-inhibition, attentional control, and affective traits. *Biological Psychology, 83*(2), 73-78. doi:10.1016/j.biopsycho.2009.10.008

Putman, P., Verkuil, B., Arias-Garcia, E., Pantazi, I., & van Schie, C. (2014). EEG θ/β-ratio as a potential biomarker for attentional control and resilience against deleterious effects of stress on attention. *Cognitive, Affective, & Behavioral Neuroscience, 14*(2), 782-791. doi:10.3758/s13415-013-0238-7

R

RAND Reading Study Group (2002). *Reading for understanding: toward a research and development program in reading comprehension*. RAND.

Raudenbush, S. W. (2009). Analyzing effect sizes: Random-effects models. In H. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), *The handbook of research synthesis and meta-analysis (*2nd ed. pp. 295-315). Russel Sage Foundation.

Rayner, K., Juhasz, B. J., & Pollatsek, A. (2005) Eye movements during reading. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 79-97). Blackwell Publishing.

Reichle, E. D., Reineberg, A. E., & Schooler, J. W. (2010). Eye movements during mindless reading. *Psychological Science, 21*(9), 1300-1310. doi:10.1177%2F0956797610378686

Rosen, L. D. (2017). The distracted student mind — enhancing its focus and attention. *Phi Delta Kappan, 99*(2), 8-14. doi:10.1177%2F0031721717734183

Rosenshine, B., & Meister, C. (1994). Reciprocal teaching: A review of the research. *Review of Educational Research, 64*(4), 479–530. doi:10.3102/00346543064004479

Rosenthal, R. (1979). The “file drawer problem” and tolerance for null results. *Psychological Bulletin, 86*, 638–641. doi:10.1037/0033-2909.86.3.638

Rubio-Aparicio, M., Sánchez-Meca, J., López-López, J. A., Botella, J., & Marín-Martínez, F. (2017). Analysis of categorical moderators in mixed-effects meta-analysis: Consequences of using pooled versus separate estimates of the residual between-studies variances. *British Journal of Mathematical and Statistical Psychology*, *70*(3), 439-456. doi:10.1111/bmsp.12092

Rummel, J., & Boywitt, C. D. (2014). Controlling the stream of thought: Working memory capacity predicts adjustment of mind-wandering to situational demands. *Psychonomic Bulletin & Review*, *21*, 1309-1315. doi:10.3758/s13423-013-0580-3

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68-78. doi:10.1037/0003-066X.55.1.68

S

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science, 18*(2), 119-144. doi:10.1007/BF00117714

Sanders, J. G., Wang, H.-T., Schooler, J. W., & Smallwood, J. (2017). Can I get me out of my head? Exploring strategies for controlling the self-referential aspects of the mind-wandering state during reading. *The Quarterly Journal of Experimental Psychology 70*(6), 1053-1062. doi:10.1080%2F17470218.2016.1216573

Saunders, P. H. (1998). *The effectiveness of paraphrasing and feedback in computer-based instruction* (Publication No. 9905104) [Doctoral dissertation, University of Memphis]. ProQuest Dissertations and Theses Global.

Schad, D. J., Nuthmann, A., & Engbert, R. (2012). Your mind wanders weakly, your mind wanders deeply: Objective measures reveal mindless reading at different levels. *Cognition, 125*(2), 179-194. doi:10.1016/j.cognition.2012.07.004

Schooler, J.W. (2002). Re-representing consciousness: Dissociations between experience and meta-consciousness. *Trends in Cognitive Sciences, 6*(8), 339-344. doi:10.1016/S1364-6613(02)01949-6

Schooler, J. W., Reichle, E. D., & Halpern, D. V. (2004). Zoning out while reading: evidence for dissociations between experience and metaconsciousness. In D. T. Levin (Ed.) *Thinking and Seeing: Visual Metacognition in Adults and Children* (pp. 203–226). MIT Press

Schooler, J., & Schreiber, C. A. (2004). Experience, meta-consciousness, and the paradox of introspection. *Journal of Consciousness Studies*, *11*(7-8), 17-39.

Scholte, E., & Noens, I. (2011). *BRIEF-A. Vragenlijst over executieve functies bij volwassenen*: *Handleiding* [BRIEF-A. Behavior Rating Inventory of Executive Function—Adult version: Manual]. Hogrefe Uitgevers B.V.

Schoots, O., & Van Tol, H. H. M. (2003). The human dopamine D4 receptor repeat sequences modulate expression. *The Pharmacogenomics Journal*, *3*, 343-348. doi:10.1038/sj.tpj.6500208

Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-wandering with and without intention. *Trends in Cognitive Sciences*, *20*(8), 605-617. doi:10.1016/j.tics.2016.05.010

Shadish, W. R., & Haddock, C. K. (2009). Combining estimates of effect sizes. In H. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), *The handbook of research synthesis and meta-analysis* (2nd ed., pp. 257-277). Russell Sage Foundation.

Shaywitz, S. E., & Shaywitz, B. A. (2008). Paying attention to reading: the neurobiology of reading and dyslexia. *Development and Psychopathology*, *20*(4), 1329-1349. doi:10.1017/S0954579408000631

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research*, *78*, 153-189. doi:10.3102%2F0034654307313795

Slavin, R. E., Cheung, A., Groff, C., & Lake, C. (2008). Effective reading programs for middle and high schools: A best-evidence synthesis. *Reading Research Quarterly, 43*, 290-322. doi:10.1598/RRQ.43.3.4

Slavin, R. E., Lake, C., Chambers, B., Cheung, A., & Davis, S. (2009). Effective reading programs for the elementary grades: A best-evidence synthesis. *Review of Educational Research, 79,* 1391-1466. doi:10.3102%2F0034654309341374

Smallwood, J. (2011). Mind-wandering while reading: Attentional decoupling, mindless reading and the cascade model of inattention. *Language and Linguistics Compass*, *5*(2), 63-77. doi:10.1111/j.1749-818X.2010.00263.x

Smallwood, J., Brown, K. S., Baird, B., Mrazek, M. D., Franklin, M. S., & Schooler, J. W. (2012). Insulation for daydreams: a role for tonic norepinephrine in the facilitation of internally guided thought. *PLoS One, 7*(4), e33706. doi:10.1371/journal.pone.0033706

Smallwood, J., Fishman, D., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin & Review, 14*(2), 230-236. doi:10.3758/BF03194057

Smallwood, J., Fitzgerald, A., Miles, L. K., & Phillips, L. H. (2009). Shifting moods, wandering minds: negative moods lead the mind to wander. *Emotion*, *9*(2), 271-276. doi:10.1037/a0014855

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36*(6), 1144-1150. doi:10.3758/MC.36.6.1144

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946-958. doi:10.1037/0033-2909.132.6.946

Smallwood, J. & Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. *Annual Review of Psychology, 66*, 487-518. doi:10.1146/annurev-psych-010814-015331

Smilek, D., Carriere, J. S., & Cheyne, J. A. (2010). Out of mind, out of sight: eye blinking as indicator and embodiment of mind wandering. *Psychological Science*, *21*(6), 786-789. doi:10.1177%2F0956797610368063

Smillie, L. D., Cooper, A. J., & Pickering, A. D. (2011). Individual differences in reward–prediction–error: extraversion and feedback-related negativity. *Social Cognitive and Affective Neuroscience*, *6*(5), 646-652. doi:10.1093/scan/nsq078

Soemer, A., Idsardi, H. M., Minnaert, A., & Schiefele, U. (2019). Mind wandering and reading comprehension in secondary school children. *Learning and Individual Differences*, *75*, 101778. doi:10.1016/j.lindif.2019.101778

Soemer, A., & Schiefele, U. (2019). Text difficulty, topic interest, and mind wandering during reading. *Learning and Instruction*, *61*, 12-22. doi:10.1016/j.learninstruc.2018.12.006

Subrahmanyam, K., Michikyan, M., Clemmons, C., Carrillo, R., Uhls, Y. T., & Greenfield, P. M. (2013). Learning from paper, learning from screens: Impact of screen reading and multitasking conditions on reading and writing among college students. *International Journal of Cyber Behavior, Psychology and Learning (IJCBPL)*, *3*(4), 1-27. doi:10.4018/ijcbpl.2013100101

Sullivan, G. M. & Feinn, R. (2012) Using Effect Size—or Why the *p* value is not enough. *Journal of Graduate Medical Education, 4*, 279-282. doi:10.4300/JGME-D-12-00156.1

Sung, Y. T., Chang, K. E., & Huang, J. S. (2008). Improving children's reading comprehension and use of strategies through computer-based strategy training. *Computers in Human Behavior, 24,* 1552-1571. doi:10.1016/j.chb.2007.05.009

Swart, E. K., Nielen, T. M. J., Shaul, S., & Sikkema-de Jong, T. M. (2020). Frontal theta/beta-ratio (TBR) as potential biomarker for attentional control during reading in healthy females. *Cognition, Brain, Behavior: An Interdisciplinary Journal, 24*(3), 187-211. doi:10.24193/cbb.2020.24.11

Swart, E. K., Nielen, T. M. J., & Sikkema-de Jong, M. T. S. (2019). Supporting learning from text: A meta-analysis on the timing and content of effective feedback. *Educational Research Review*, *28,* 100296. doi:10.1016/j.edurev.2019.100296

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*, 295-312. doi:10.1016/0959-4752(94)90003-5

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251-296. doi:10.1023/A:1022193728205

T

Tabachnick, B. G., & Fidell, A. S. (2007). *Using multivariate statistics.* Pearson Education.

Takacs, Z. K., Swart, E. K., & Bus, A. G. (2014). Can the computer replace the adult for storybook reading? A meta-analysis on the effects of multimedia stories as compared to sharing print stories with an adult. *Frontiers in Psychology*, *5*, 1366. doi:10.3389/fpsyg.2014.01366

Takacs, Z. K., Swart, E. K., & Bus, A. G. (2015). Benefits and pitfalls of multimedia and interactive features in technology-enhanced storybooks: A meta-analysis. *Review of Educational Research*, *85*, 698-739. doi:10.3102%2F0034654314566989

Ter Beek, M., Brummer, L., Donker, A. S., & Opdenakker, M. C. J. (2018). Supporting secondary school students' reading comprehension in computer environments: A systematic review. *Journal of Computer Assisted Learning, 34*, 557-566. doi:10.1111/jcal.12260

Tilstra, J., McMaster, K., Van den Broek, P., Kendeou, P., & Rapp, D. (2009). Simple but complex: Components of the simple view of reading across grade levels. *Journal of Research in Reading*, *32*(4), 383-401. doi:10.1111/j.1467-9817.2009.01401.x

Tripp, G., & Wickens, J. R. (2008). Research Review: Dopamine transfer deficit: a neurobiological theory of altered reinforcement mechanisms in ADHD. *Journal of Child Psychology & Psychiatry*, *49*(7), 691–704. doi:10.1111/j.1469-7610.2007.01851.x

Tsafou, K. E., Lacroix, J. P., Van Ee, R., Vinkers, C. D., & De Ridder, D. T. (2017). The relation of trait and state mindfulness with satisfaction and physical activity: A cross-sectional study in 305 Dutch participants. *Journal of Health Psychology*, *22*(10), 1221-1232. doi:10.1177%2F1359105315624748

U

Ullsperger, M. (2010). Genetic association studies of performance monitoring and learning from feedback: The role of dopamine and serotonin. *Neuroscience & Biobehavioral Reviews*, *34*(5), 649-659. doi:10.1016/j.neubiorev.2009.06.009

Unrau, N. J., & Quirk, M. (2014). Reading motivation and reading engagement: Clarifying commingled conceptions. *Reading Psychology*, *35*(3), 260-284. doi:10.1080/02702711.2012.684426

U.S. News (2020). *Best Countries for Education.* https://www.usnews.com/news/best-countries/best-education

Uzzaman, S., & Joordens, S. (2011). The eyes know what you are thinking: eye movements as an objective measure of mind wandering. *Consciousness and Cognition*, *20*(4), 1882-1886. doi:10.1016/j.concog.2011.09.010

V

Van den Broek, P. & Gustafson, M. (1999). Comprehension and memory for texts: Three generations of reading research. In S. R. Goldman, A. C. Graesser, and P. van den Broek (Eds.), *Narrative comprehension, causality, and coherence: Essays in honor of Tom Trabasso* (pp. 15-34). Lawrence Erlbaum Associates, Inc.

Van den Broek, P., Lorch, R. F., Linderholm, T., & Gustafson, M. (2001). The effects of readers' goals on inference generation and memory for texts. *Memory & Cognition*, *29*(8), 1081-1087. doi:10.3758/BF03206376

Van den Broek, P., Rapp, D. N., & Kendeou, P. (2005). Integrating memory-based and constructionist processes in accounts of reading comprehension. *Discourse Processes*, *39*, 299-316. doi:10.1080/0163853X.2005.9651685

Van den Broek, P., Virtue, S., Everson, M. G., Tzeng, Y., & Sung, Y. C. (2002). Comprehension and memory of science texts: Inferential processes and the construction of a mental representation. In J. Otero, J. A. Léon, A. C. Graesser (Eds.) *The psychology of science text comprehension* (pp. 131-154). Routledge.

Van der Kleij, F. M., Feskens, R. C., & Eggen, T. J. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research*, *85*, 475-511. doi:10.3102%2F0034654314564881

Van der Kleij, F. M., Eggen, T. J., Timmers, C. F., & Veldkamp, B. P. (2012). Effects of feedback in a computer-based assessment for learning. *Computers & Education*, *58*, 263-272. doi:10.1016/j.compedu.2011.07.020

Van der Stigchel, S (2018). *Concentratie: Gefocust blijven in tijden van afleiding* [Concentration: Staying focused in times of distraction]. Maven Publishing B.V.

Van Son, D., Angelidis, A., Hagenaars, M. A., van der Does, W., & Putman, P. (2018). Early and late dot-probe attentional bias to mild and high threat pictures: Relations with EEG theta/beta ratio, self-reported trait attentional control, and trait anxiety. *Psychophysiology*, *55*(12), e13274. doi:10.1111/psyp.13274

Van Son, D., De Blasio, F. M., Fogarty, J. S., Angelidis, A., Barry, R. J., & Putman, P. (2019a). Frontal EEG theta/beta ratio during mind wandering episodes. *Biological Psychology, 140*, 19-27. doi:10.1016/j.biopsycho.2018.11.003

Van Son, D., de Rover, M., De Blasio, F. M., van der Does, W., Barry, R. J., & Putman, P. (2019b). Electroencephalography theta/beta ratio covaries with mind wandering and functional connectivity in the executive control network. *Annals of the New York Academy of Sciences*, *1452*(1), 52-64. doi:10.1111%2Fnyas.14180

Van Steensel, R., Van der Sande, L., Bramer, W., & Arends, L. (2016). *Effecten van leesmotivatie-interventies: Uitkomsten van een meta-analyse* [Effects of reading motivation interventions: Outcomes of a meta-analysis]. Erasmus University Rotterdam.

Viechtbauer, W. (2007). Accounting for heterogeneity via random-effects models and moderator analyses in meta-analysis. *Journal of Psychology*, *215*, 104-121. doi:10.1027/0044-3409.215.2.104

Vijayraghavan, S., Wang, M., Birnbaum, S. G., Williams, G. V., & Arnsten, A. F. (2007). Inverted-U dopamine D1 receptor actions on prefrontal neurons engaged in working memory. *Nature Neuroscience*, *10*(3), 376-384. doi:10.1038/nn1846

W

Wadley, J. (2015, November 23). *Dopamine: New theory integrates its role in learning, motivation.* University of Michigan News. https://news.umich.edu/dopamine-new-theory-integrates-its-role-in-learning-motivation/

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory: Is younger, better? *Developmental Review*, *32*(4), 360-387. doi:10.1016/j.dr.2012.07.001

Weissman, D. H., Roberts, K. C., Visscher, K. M., & Woldorff, M. G. (2006). The neural bases of momentary lapses in attention. *Nature Neuroscience, 9*(7), 971-978. doi:10.1038/nn1727

Westbrook, A. & Braver, T. S. (2016). Dopamine does double duty in motivating cognitive effort. *Neuron, 89*, 695-710. doi:10.1016/j.neuron.2015.12.029

Weyandt, L. L., & DuPaul, G. J. (2008). ADHD in college students: Developmental findings. *Developmental Disabilities Research Reviews*, *14*(4), 311-319. doi:10.1002/ddrr.38

Wigfield, A., & Guthrie, J.T. (1997). Relations of children's motivation for reading to the amount and breadth of their reading, *Journal of Educational Psychology*, *89*, 420–432. doi:10.1037/0022-0663.89.3.420

Wigfield, A., Gladstone, J. R., & Turci, L. (2016). Beyond cognition: Reading motivation and reading comprehension. *Child Development Perspectives, 10*(3), 190-195. doi:10.1111/cdep.12184

Wijekumar, K. K., Meyer, B. J., & Lei, P. (2013). High-fidelity implementation of web-based intelligent tutoring system improves fourth and fifth graders content area reading comprehension. *Computers & Education*, *68*, 366-379. doi:j.compedu.2013.05.021

Wolf, M. (2018). *Reader, come home: The reading brain in a digital world.* HarperCollins.

Wolf, M. (2018, August 25). *Skim reading is the new normal. The effect on society is profound.* The Guardian*.*

Wolters, C. A., Barnes, M. A., Kulesz, P. A., York, M., & Francis, D. J. (2017). Examining a motivational treatment and its impact on adolescents' reading comprehension and fluency. *The Journal of Educational Research*, *110*(1), 98-109. doi:10.1080/00220671.2015.1048503

X

Xu, J., & Zhong, B. (2018). Review on portable EEG technology in educational research. *Computers in Human Behavior*, *81*, 340-349. doi:10.1016/j.chb.2017.12.037

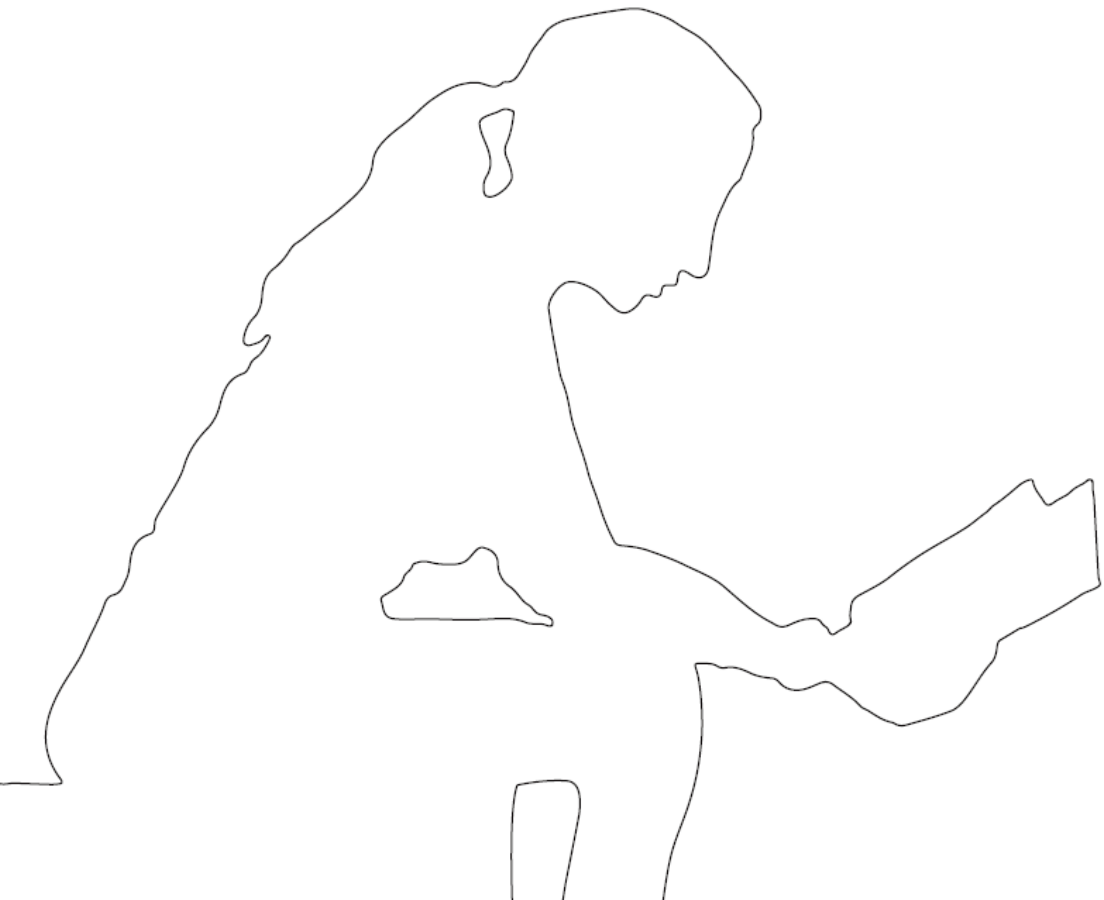
Z

Zanesco, A. P., King, B. G., MacLean, K. A., Jacobs, T. L., Aichele, S. R., Wallace, B. A., Smallwood, J., Schooler, J. W., & Saron, C. D. (2016). Meditation training influences mind wandering and mindless reading. *Psychology of Consciousness: Theory, Research, and Practice*, *3*(1), 12-32. doi:10.1037/cns0000082

Zhang, T., Mou, D., Wang, C., Tan, F., Jiang, Y., Lijun, Z., & Li, H. (2015). Dopamine and executive function: Increased spontaneous eye blink rates correlate with better set-shifting and inhibition, but poorer updating. *International Journal of Psychophysiology*, *96*(3), 155-161. doi:10.1016/j.ijpsycho.2015.04.010

Zhou, P., Prat, C., Yamasaki, B. L., & Stocco, A. (2020). Monitoring of attentional oscillations through Spectral Similarity Analysis predicts reading comprehension. *Brain and Language*, *200*, 104709. doi:10.1016/j.bandl.2019.104709

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science*, *6*(5), 292-297. doi:10.1111%2Fj.1467-9280.1995.tb00513.x



Nawoord (Epilogue)

Nawoord

(Epilogue)

Een Afrikaanse wijsheid luidt “It takes a village to raise a child”. Kortom, de gehele gemeenschap heeft invloed op de ontwikkeling van een kind. Ontwikkeling hoort ook centraal te staan in een promotietraject. Nu mijn proefschrift zijn definitieve vorm heeft bereikt, blik ik, in lijn met deze wijsheid, terug op mijn ‘dorp’. Het was een interessant en divers dorp, waarin ieder een eigen invloed had op mijn ontwikkeling en die van dit proefschrift. Een aantal van hen wil ik hieronder bedanken.

Marga, jij hebt mijn interesse voor wetenschappelijk onderzoek aangewakkerd en mede dankzij jou heb ik die interesse tijdens mijn promotietraject verder kunnen ontwikkelen en vasthouden, ook op momenten waarop dat niet vanzelfsprekend was. Bedankt voor al je ondersteuning bij de onderzoeken, het schrijven en alle zaken daaromheen!

Een dorp kan niet zonder mensen met levenservaring en de daaruit voortkomende wijze lessen. Chris, dank voor jouw promotorschap en wijze lessen als wetenschapper en mens. Eric, ik ben dankbaar voor jouw komst in het dorp. Jouw besluitkracht en de wijze (koopvaardij)lessen van jou en de mensen om jou heen hebben geholpen om door te blijven zetten en vertrouwen te houden in een goede afronding.

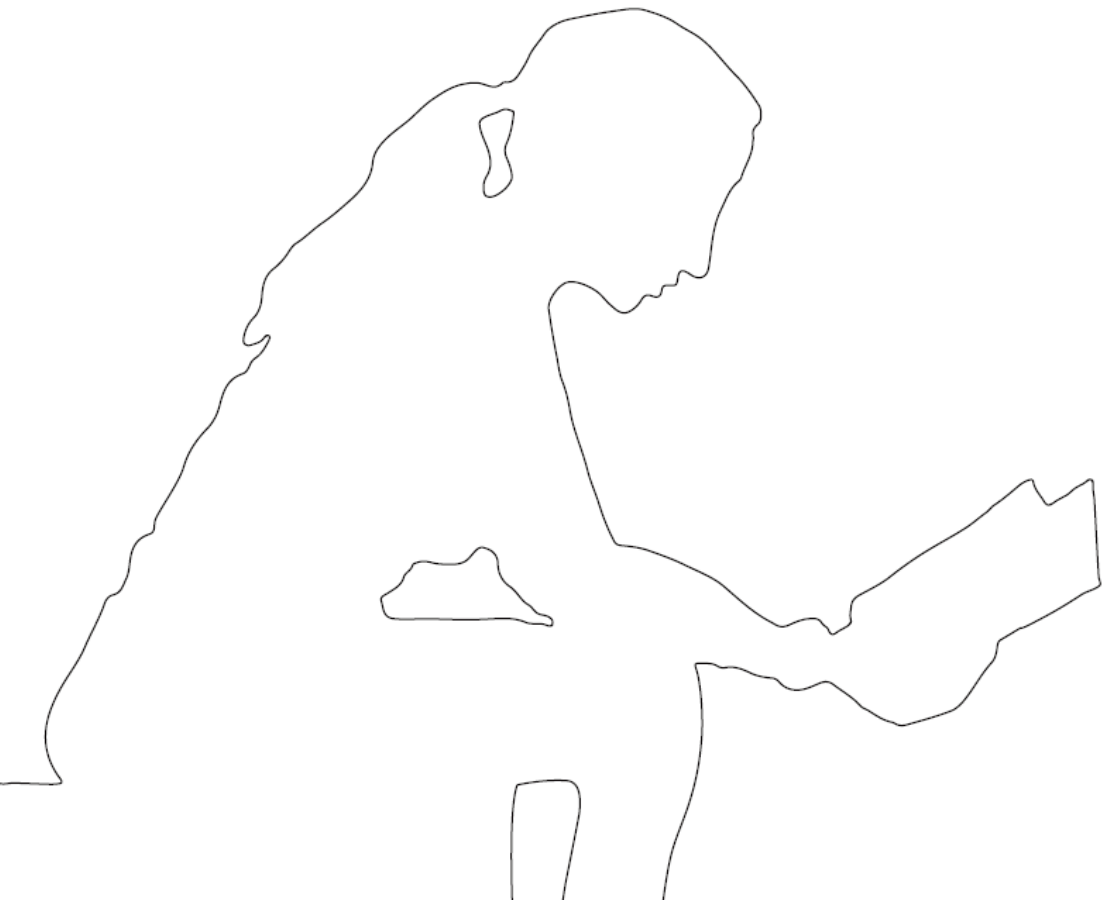
Lieve Heleen, Thijs, Rachel en Inge, ons rijtje proefschriften is eindelijk compleet. Bedankt voor alle gezelligheid op de afdeling en daarbuiten! Lieve Marianne en andere collega’s op de afdeling, bedankt voor de samenwerking binnen onderzoek en onderwijs, de goede gesprekken en gezelligheid.

Aan de onderzoeken in dit proefschrift hebben veel studenten meegewerkt, zowel als participant als onderzoeker. Bedankt voor jullie inzet! Onze samenwerking heeft me zeer geïnspireerd en ik hoop dat ik jullie op mijn beurt heb kunnen inspireren.

Tot zover het ‘Leidse deel’ van het dorp. Lieve vrienden, familie en schoonfamilie, bedankt voor al jullie oprechte interesse en steun al die jaren. Mam, pap, bedankt dat jullie jarenlang met zoveel geduld de verhalen hebben aangehoord, hebben meegeleefd en jullie trots lieten blijken. Deborah, bedankt dat je daarnaast proefkonijn wilde zijn voor en tijdens mijn onderzoeken.

Lieve Menno, bedankt voor je geduld, begrip, interesse, het luisterende oor telkens weer en alle mooie momenten samen buiten de tijd die ik aan mijn promotietraject besteedde.

Lieve Sophie, zo klein als je bent heb je al zo’n grote invloed gehad. Jij hebt laten zien welke dingen het meest belangrijk en waardevol zijn en hoe mooi aandacht echt is, niet alleen tijdens lezen (hoewel we dat samen maar al te graag doen).



Curriculum Vitae

Curriculum Vitae

Elise Karolina Swart, geboren op 19 juni 1991 te Dordrecht, behaalde in 2009 haar eindexamen van het gymnasium aan het Stedelijk Dalton Lyceum te Dordrecht. In datzelfde jaar begon zij aan de bacheloropleiding Pedagogische Wetenschappen aan de Universiteit Leiden, waarbinnen zij koos voor een specialisatie in de Leerproblemen. Ze behaalde haar bachelor-graad in 2012 en startte aansluitend daarop de Research Master Developmental Psychopathology in Education and Child Studies aan de Universiteit Leiden. Ter afronding van haar master schreef zij een scriptie, getiteld "Technology-enhanced stories as word learning support for children at risk: A meta-analysis", die werd bekroond met drie scriptieprijzen: de Emile scriptieprijs Pedagogische Wetenschappen 2014, de Scriptieprijs 2014 van de Faculteit der Sociale Wetenschappen en de landelijke NVO Scriptieprijs 2014. In december 2013 behaalde ze haar Master of Science en in januari 2014 startte ze als promovenda op de afdeling Leer- en Gedragsproblemen in het Onderwijs. Haar promotieonderzoek richtte zich op aandacht, feedback en begrijpend lezen. De resultaten van dit promotieonderzoek zijn in dit proefschrift beschreven.

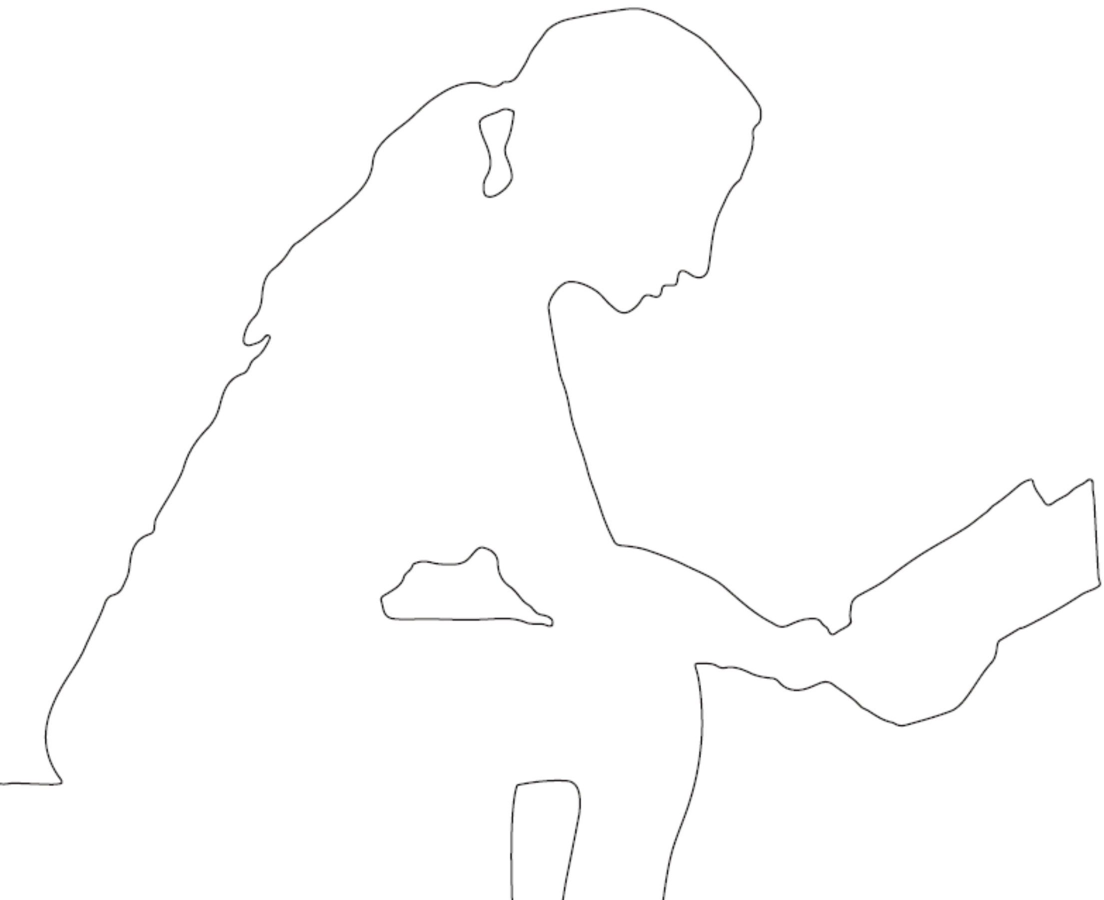
Naast haar promotieonderzoek verzorgde Elise de begeleiding van bachelor- en masterscripties en colleges, werkgroepen en practica voor diverse bachelor- en mastercursussen binnen de opleiding Pedagogische Wetenschappen. In 2017 behaalde ze haar Basiskwalificatie Onderwijs. In 2018 ontving zij, samen met dr. Marga Sikkema-de Jong, een Grassroot ten behoeve van onderwijsinnovatie t.w.v. €1000 om een mobiele EEG headset binnen het onderwijs in te zetten, zodat meer studenten ervaring konden opdoen met psychofysiologische maten (in het bijzonder EEG) binnen hun bachelor- en masteronderzoeken.

Elise heeft haar onderzoek gepresenteerd in binnen- en buitenland, onder andere tijdens de 7th International Graduate School on Literacy Acquisition van de Society for the Scientific Study of Reading in 2015, de Summer School on Reading and Learning in the Digital World aan de Universiteit van Würzburg in 2017 en het jaarlijkse wetenschappelijke congres van de Society for the Scientific Study of Reading in Brighton 2018. Naast haar onderzoeks- en onderwijsactiviteiten is ze in 2016 en 2017 lid geweest van het organisatiecomité van de VNOP-CAS-ISED Research Days en was ze betrokken bij de organisatie van de Nederlands-Vlaamse Interacademiale Leerproblemen 2019.

Naast publicaties en presentaties binnen wetenschappelijke kringen, heeft Elise zich ingezet voor de vertaling van wetenschappelijke inzichten naar de onderwijspraktijk, door artikelen over voorlezen, leesonderwijs en leesvaardigheid te schrijven voor de Kennisrotonde en het platform Leraar24 en lezingen te verzorgen voor vrijwilligers van de VoorleesExpress en Stichting Voorlezen. Van oktober 2017 t/m mei 2018 is Elise daarnaast werkzaam geweest als junior beleidsmedewerker binnen het domein Sociale- en

Geesteswetenschappen van de Nederlandse organisatie voor Wetenschappelijke Onderzoek (NWO).

Sinds juli 2020 is Elise werkzaam als programma- en beleidsmedewerker op de afdeling Vrij Onderzoek en Wetenschapsdomein van het NWO-domein Sociale en Geesteswetenschappen.



List of Publications

List of Publications

International refereed journals

- **Swart, E. K.** & Sikkema-de Jong, T. M. (under review). The effects of increased dopamine-levels on attentional control during reading and reading comprehension.

- **Swart, E. K.**, Nielen, T. M. J., & Sikkema-de Jong, T. M. (under review). Explaining the effect of feedback on reading comprehension: A meta-analysis on the effects of feedback on the use of reading strategies and motivational aspects.

- **Swart, E. K.**, Nielen, T. M. J., Shaul, S., & Sikkema-de Jong, T. M. (2020). Frontal theta/beta-ratio (TBR) as potential biomarker for attentional control during reading in healthy females. *Cognition, Brain, Behavior: An Interdisciplinary Journal. 24*(3), 187-211. doi:10.24193/cbb.2020.24.11

- **Swart, E. K.**, Nielen, T. M. J., & Sikkema-de Jong, M. T. (2019). Supporting learning from text: A meta-analysis on the timing and content of effective feedback. *Educational Research Review, 28*, 100296. doi:10.1016/j.edurev.2019.100296

- Takacs, Z. K., **Swart, E. K**. & Bus, A. G. (2015). Benefits and pitfalls of multimedia and interactive features in technology-enhanced storybooks. A meta-analysis. *Review of Educational Research, 85* (4), 698-739. doi:10.3102/0034654314566989

- Takacs, Z. K., **Swart, E. K.** & Bus, A. G. (2014). Can the computer replace the adult for storybook reading? A meta-analysis on the effects of multimedia stories as compared to sharing print stories with an adult. *Frontiers in Psychology, 5,* 1366. doi:10.3389/fpsyg.2014.01366

Book chapters

- **Swart, E. K.** (2015). Verhalen met technologie als hulpmiddel om nieuwe woorden te leren: Een meta-analyse. In D. Schram, *Hoe maakbaar is de lezer?* (pp. 109-128). Delft, Nederland: Uitgeverij Eburon.

National (refereed) journals

- Sikkema-de Jong M.T. & **Swart E. K.** (2017). App, noot, mies. Leerzame voorleesapps kiezen. *De Wereld van het Jonge Kind, 45*, 16-19.

- Takacs, Z. K. & **Swart, E. K.** (2016). A multimédiás mesék potenciálja a kétnyelvű, migráns családokból származó óvodások nyelvi fejlesztése szempontjából: metaanalízis [The Potential of Multimedia Stories for Fostering the Language Skills of Bilingual, Immigrant Preschoolers: A Meta-Analysis]. Altalanos Nyelveszeti Tanulmanyok, *28,* 279-294.
- **Swart E. K.** (2015). Gedigitaliseerde verhalen als hulpmiddel om nieuwe woorden te leren: Een meta-analyse. *Orthopedagogiek: Onderzoek en Praktijk, 54* (8), 340-349.
- **Swart, E. K.** (2015). Gedigitaliseerde verhalen als hulpmiddel bij het leren van nieuwe woorden. *NVO Bulletin, 16* (1), 10-11.

Other

- Kennisrotonde (2020). *Welke relatie bestaat er tussen (een zwakke) woordenschat en technisch lezen? (KR. 821)*. Nederlands Regieorgaan Onderwijsonderzoek (NRO).
- Nationaal Regieorgaan Onderwijsonderzoek (2020). *Leesmotivatie: investeren in de wil om te lezen.* Leraar24. https://www.leraar24.nl/2621612/leesmotivatie-investeren-in-de-wil-om-te-lezen/
- **Swart, E. K**. & Stichting Voorlezen (2020). *Kennisdossier digitale prentenboeken.* Stichting Voorlezen.
- Kennisrotonde (2018). *Welk verband bestaat er tussen tutorlezen en de ontwikkeling van technische leesvaardigheid? Wat zijn werkzame ingrediënten bij tutorlezen? (KR. 436).* Nederlands Regieorgaan Onderwijsonderzoek (NRO).
- Kennisrotonde (2017). *Welke strategie is het meest effectief voor het aanleren van auditieve synthese ("plakken") bij technisch lezen en wanneer kun je het beste starten met het aanleren hiervan? (KR. 247)*. Nederlands Regieorgaan Onderwijsonderzoek (NRO).