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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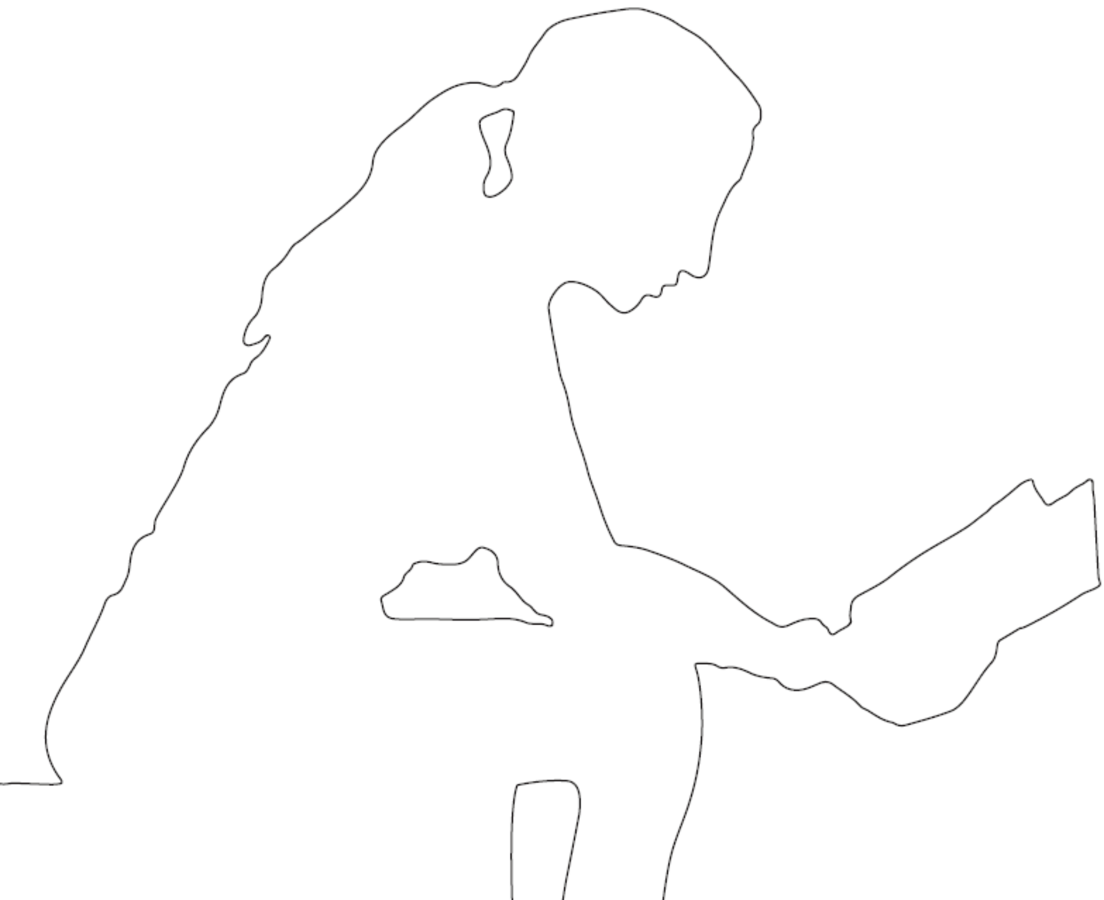
Title: Mind the reading mind: a multifaceted and methodologically diverse approach to investigating the role of attentional control and feedback in reading comprehension
Issue Date: 2021-06-08



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.

6

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'.