Jana Lüdtke, Johanna K. Kaakinen, Arthur M. Jacobs

Contextual Meaning-Making in Reading: The Role of Affect

Abstract: Emotions play a crucial role in how readers process, comprehend, and experience texts. This chapter focuses on what we have learned about emotional aspects of reading by using eye tracking, a methodology that provides detailed information about the time-course of reading processes as they occur online. The chapter first introduces basic emotion concepts relevant for reading research. It then describes key measures of eye movements used in previous research, focusing on sentence and text comprehension. We then briefly review previous eye tracking research on the role of emotions in reading conducted at three levels: word, sentence, and text. It appears that while word-level emotion effects have received quite a lot of attention, much less empirical work has been conducted on sentence and text-level phenomena. This lack of empirical evidence is reflected in a dearth of theoretical accounts, which currently are still under development. Thus, there is a clear need for vigorous empirical research to help advance theoretical work on emotional aspects of reading. This chapter highlights the importance of using naturalistic texts and the need for further development in advanced exploratory, predictive, and explanatory computational methods and models in order to foster understanding of the emotional aspects of reading.

Theoretical Views on Emotions and Reading

Literature presents a unique set of depictive representations of emotional experiences, providing instructions for the mental simulation of experiences that can produce affective, empathic, and aesthetic responses in readers (Hogan, 2011; Jacobs, 2015a; Schrott & Jacobs, 2011). Thus, the role of emotions in readers' processing, comprehending, and experiencing of texts cannot be underestimated. A reader may experience the crux of emotions induced by a text's form or content, and previous research has theorized how different texts may provoke *evaluative*, *aesthetic*, *narrative* or even *self-modifying feelings* in readers (e. g., Kneepkens & Zwaan, 1995; Miall & Kuiken, 2002; Oatley, 1995). For example, a well-written novel may induce feelings of suspense as the reader becomes immersed in the story and feels empathy towards a character in the text (narra-

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tive feeling). This, in turn, may increase the reader's appreciation of the author's writing style (aesthetic feeling, Kneepkens & Zwaan, 1995). In addition to literary narratives, and perhaps even more so, poetry can induce feelings that reflect the mood depicted in the text or appreciation for its form, depending on the foregrounding and backgrounding textual features (Jacobs et al., 2016; Lüdtke et al., 2014). However, when considering emotions during reading, it should be remembered that not only the text features but also the reader's expectations, prior beliefs, and knowledge contribute to how a text is received. Readers may experience emotions that stem from their epistemic beliefs, such as surprise or confusion when reading information that conflicts with their prior expectations (Muis et al., 2015). The genre of the text is of course important, too: readers may not be that concerned if implausible things happen in fiction (e. g., Hsu et al., 2015), but would (and should) be concerned if such things were reported in a physics textbook or the news. Moreover, the context of reading may activate expectations that provoke emotional reactions, such as when a student is reading a novel for a literature class and feels anxious about possibly failing in the upcoming exam (Pekrun, 2006).

According to a standard view, an emotional response is initiated by an appraisal of personal significance or relevance of an event, which leads to an emotional response involving a subjective experience, physiology, and behavior (Mauss & Robinson, 2009). Emotions are often described with the help of two fundamental dimensions that organize emotional responses (Posner et al., 2005): valence (positive vs. negative) and arousal (activation). For example, feeling calm or serene after reading a poem could be described as a positive feeling that is relatively low in arousal, whereas feeling tense when reading a horror story would probably be a negative and highly arousing emotion. Some researchers favor categorizing emotional experiences with discrete emotion labels such as anger, disgust, fear, sadness, surprise, and happiness (e. g., Ekman & Cordaro, 2011). But, especially when describing the complex emotions that occur during literary reading, these categories might not be sufficient for capturing the full reading experience. Instead, a more comprehensive approach in which emotional experience is measured as a high-dimensional construct is needed (see Cowen et al., 2019). For example, Cowen and Keltner (2017) analyzed self-reported emotional responses to video clips and found 27 distinct categories of emotional experience, including emotions such as aesthetic appreciation and entrancement. The researchers suggested that, even though emotional experiences can be represented in semantic spaces characterized by distinct emotion labels, the boundaries between categories are fuzzy and emotional experiences might best be described by gradients (e. g., from calmness to aesthetic appreciation to awe).

Choosing a theoretical approach to emotions is important, as it guides methodological decisions about how emotional responses are measured. For example, when developing a questionnaire for aesthetic emotions, Schindler et al. (2017) decided to retain 21 of their original 24 emotion categories even though the empirical data suggested that the most parsimonious model contains only seven factors. The rationale for this decision was theoretical: in order to describe the richness of an aesthetic experience, the authors believed that they needed more specific categories than can be captured by superordinate emotion categories of negative emotions, prototypical aesthetic emotions, epistemic emotions, animation, nostalgia/relaxation, sadness, and amusement. It is important to note that measuring subjective experience with a questionnaire captures only one facet of emotion. If, for example, the brain of a reader really could compute 21 distinct aesthetic emotional responses, each should be characterized by specific patterns of neural, physiological, and behavioral responses. But we know of no such evidence, and it is very likely that different people can produce many different words for one and the same emotion. On the other hand, at the level of verbally expressible subjectivity at least, a goal keeper's fear of a penalty is not the same as a mother's fear of giving birth or a penitent's fear of hell. Thus, "It is time for clinicians and scientists to acknowledge the origin of each emotional state and replace the currently popular English terms with new concepts that specify the causes of the separate members of an emotional family" (Kagan, 2010, p. 92).

An important process in the emotional experience is appraisal: the cognitive evaluation of the emotion event in the specific situation from the individual's perspective (e. g., Scherer, 2009). In a reading context, "emotion event" refers to the emotional responses induced by the text-context-reader situation. For example, even though a detailed graphic description of physical violence in a Stephen King story might initially induce a quick reaction of disgust, the reader might still feel a pleasurable emotion of entertainment and/or admiration for the author's skill in creating suspense (Kneepkens & Zwaan, 1995). Actually observing a similar scene in the real world would result in a completely different reaction.

Recently, there has been growing interest in developing theoretical models that specifically describe the role of emotions in reading by combining psychological emotion theories with models of literary reading and reading comprehension (Bohn-Gettler, 2019; Jacobs, 2015a). The Neurocognitive Poetics Model (NCPM) proposed by Jacobs (2015a) combines empirical evidence from the behavioral and neurosciences with theoretical views on aesthetic experiences to form a model that can predict the interplay of affective and cognitive processes during literary reading. The NCPM assumes that different quantifiable text, con-

text, and personality features determine which emotions a reader is likely to experience. For example, emotional narratives using familiar situation models typically induce higher immersion, resulting in higher empathy towards the story characters and more vivid emotional experiences, while (poetic) texts full of foregrounding features may evoke aesthetic responses (see also Kuiken & Douglas, 2017). The PET (Process, Emotion, Task) framework proposed by Bohn-Gettler (2019) combines emotion theories with the Construction-Integration model (Kintsch, 1998) and describes how reader emotions influence text comprehension. The core idea of the model is that the effects of emotions on text comprehension depend on the type of emotion, the type of comprehension processes involved, and the task the reader has in mind. Positive and negative emotions are thought to result in different processing patterns influencing comprehension processes (e. g., elaboration, inference-making).

Eye Movements Reveal the Time Course of Basic Reading Processes

Eye movement recordings can reveal a wealth of information about reading processes as they unfold across time (see Hyönä & Kaakinen, 2019; Kaakinen, 2017; Rayner, 2009). During reading the eyes typically move in the reading direction in jerky movements called saccades and stop (i. e., fixate) on almost every word in the text. The duration of fixations is very brief, typically only 200–250 milliseconds. Some words are fixated more than once and thus are gazed at longer: for example, long and unusual words typically receive more than one fixation. At the end of a sentence, readers usually pause. This is referred to as the sentence wrap-up effect, which reflects integrative processing at the sentence end (Rayner et al., 2000). When the reader's eyes reach the end of a line, the eyes are sent to the beginning of the next line, producing a long saccade against the direction of reading (return sweep). Occasionally a reader makes regressions that can be directed either to the already fixated word, to a word within the same sentence, or to previous parts of the text (Inhoff et al., 2019). A standard practice is to compute different fixation time measures to describe the temporal course of processing words or parts of text.

Most eye movement studies to date have examined the reading of single words embedded either in a sentence or short textual context. In these studies, separate measures reflecting the first-pass reading of the word (e. g., likelihood of skipping, first fixation duration, gaze duration) and the likelihood and the

duration of revisits to the word are typically reported (e. g., second path reading time, regression path duration, total fixation time). First-pass reading measures are thought to reflect the speed of lexical access, whereas measures indicating revisits to a word are considered as indices of either delayed lexical access or integrative processing at the level of the phrase. A wealth of previous research demonstrates that fixation duration on a given word is influenced by factors such as word length, frequency, age of acquisition, and predictability and plausibility of the word in the given sentence context (see Rayner, 1998, 2009).

While word-based measures give a detailed view of the processing of single words, especially with longer text materials it might be useful to examine the processing of larger segments of text, like phrases or sentences (Hyönä et al., 2003). As with word-based measures, it is useful to separate measures for first-pass reading and later look-backs to and from a sentence. Previous research suggests that longer first-pass fixation times on a sentence reflect the immediate processing of the information expressed in the sentence, whereas look-backs extending to previous segments of text are likely to reflect strategic processing (see Hyönä & Kaakinen, 2019). Look-backs can be considered as strategic processing because (a) readers are aware of whether they look back to and reread specific parts of text, (b) look-backs are thus purposefully directed towards parts of text that are relevant for comprehension, and (c) they seem to facilitate or even be essential for comprehension (Hyönä & Nurminen, 2006; Fechino et al., 2020; Olkoniemi et al., 2019; Schotter et al., 2014).

As with any reaction time measure, interpreting the meaning of changes in eye fixation times on a word or sentence must be done with caution. For instance, a longer fixation time might reflect either more effortful processing leading to successful word recognition or comprehension of a sentence, or a failure in word decoding due to a comprehension problem. That is why we recommend combining eye movement measures with outcome measures, such as comprehension questions, text recall, or some other measure reflecting the quality of processing. Even though fixation time measures provide temporally accurate information about the reading of words and sentences, sometimes it might be fruitful to analyze the scanpaths, that is, the transitions a reader makes between different parts of text during reading (Von der Malsburg & Vasishth, 2011). Finally, eye tracking allows collecting other data than eye movements. For example, changes in pupil size and the occurrence of eye blinks reflect attentional processes and emotional arousal (Eckstein et al., 2017; Võ et al., 2008). However, these measures have not been extensively used to study reading behavior. In sum, eye tracking provides a wealth of different measures that can be used to study reading-related processes. Eye fixation times provide temporally accurate information about moment-to-moment processes underlying reading; scanpath

analyses reveal the pattern of gaze shifts between different parts of text; and pupil size and blink rates potentially reflect attentional and emotional processes, although the utility of the latter in reading research still needs more empirical study.

To date, eye movement recordings have been used only rarely to examine emotion effects in reading. In the following, we provide a brief overview of the studies that looked at emotion effects during single word reading, followed by research on reading of paragraphs and longer text.

Reading Emotional Words

Most studies on affective effects at the level of single words used standard word recognition tasks like lexical decisions or naming (for review: Citron, 2012; Jacobs et al., 2015). Behavioral studies focusing on differences in reaction times, brain-electrical studies focusing on differences in event-related potentials, and fMRI studies focusing on activation differences during the processing of emotional words compared to neutral words have highlighted various replicable effects in various time windows or brain regions (e. g., Hofmann et al., 2009; Kissler et al., 2009; Kousta et al., 2009; Kuchinke et al., 2005; Kuperman et al., 2014; Palazova et al., 2011; Scott et al., 2009). In general, most studies reported a processing advantage for emotional words compared to neutral ones, an effect often more pronounced for positive than for negative words (e. g., Estes & Verges, 2008; Hofmann et al., 2009; Kanske & Kotz, 2007; Kuchinke et al., 2005; Palazova et al., 2011; Scott et al., 2009). At the behavioral level, the processing advantage of emotional words in general and especially for positive words is reflected in shorter reaction times for emotional words compared to neutral words and for positive words compared to negative words. This processing benefit, called positivity bias, was also replicated in studies presenting words embedded in meaningful phrases or sentences (e. g., Bayer et al., 2010; Delaney-Busch & Kuperberg, 2013; Ding et al., 2014; Lüdtke & Jacobs, 2015; Scott et al., 2012). Besides this processing advantage, several studies also demonstrated that emotional words have some attention grabbing properties and that the neural signature of this prioritized processing of emotional words seems to be similar to the signature observed for the prioritized processing of other emotional stimuli such as images or faces (e. g., Herbert et al., 2008; Keuper et al., 2014; Kissler & Herbert, 2013; Trauer et al., 2015; Wegrzyn et al., 2017). The prioritized and enhanced processing of emotional words has been explained, for example, with motivational aspects assuming enhanced resource

allocation and natural selective attention to intrinsically relevant stimuli (e. g., Bradley et al., 2012).

One of the first eye tracking studies focusing on effects of emotional words embedded in sentences was done by Hyönä and Häikiö in 2005. The authors used words with negative valence and a high arousal value, such as obscene, sex-related, and curse words, to test the so-called parafoveal semantic processing hypothesis. That means, in contrast to the above-mentioned studies, that the authors did not directly measure the processing of emotional compared to neutral words, but tested whether the parafoveal preview of an emotional word compared to a neutral word influenced the processing of a fixated neutral target word. Participants read simple sentences including an emotion word or a neutral word which was replaced by a neutral target word every time the participants made the saccade toward this target word, which means that the emotional and neutral words were only seen parafoveally. In contrast to their hypothesis, the authors found no effects of the emotional content of the parafoveal preview, neither in fixation durations around the target nor in pupil size. These null effects were not the result of weak emotion potentials of the test material, given the high-arousing sex- and threat-related words. Rather, it is still under debate whether semantic properties can be picked up during parafoveal preprocessing, especially when reading alphabetical languages (cf. Vasilev & Angele, 2017). An alternative explanation in terms of opposite processes could be that especially high arousing taboo words do both capture and repel attention (Yan & Sommer, 2015).

The first eye tracking study directly focusing on processing differences of emotional and neutral words embedded in sentences seems to be Scott et al.'s from 2012. In this study, participants read simple sentences containing an emotionally positive (e. g., lucky), negative (e. g., angry), or neutral (e. g., plain) word. In accordance with the well-known processing advantage of emotional words observed in studies on single word processing described above, first fixation times and gaze duration times on emotion words were shorter than fixation times on neutral words. Taking into account that the emotionality of a word interacts with word frequency (observed especially at early processing stages in single word processing, e. g., Palazova et al., 2011; Scott et al., 2009), Scott et al. (2012) also manipulated the word frequency and found shorter fixation durations for emotional words for both low frequent and high frequent positive words, for low frequent negative words, but not for high frequent negative words. The interaction between words emotionality and word frequency indicated that linguistic sources of information like word frequency modulate the conditions under which emotional processing benefits emerge, especially for negative words. The study by Sheikh and Titone (2013) manipulating emotional-

ity, word frequency, and concreteness replicated and extended the results of Scott et al. (2012). It showed that the emotional processing benefit during early processing stages (measured by gaze duration) was more pronounced for low frequency and less concrete words, whereas at later processing stages (measured by second pass reading times) the emotional processing benefit could be observed for all words independently of word frequency and level of concreteness. The study by Knickerbocker et al. (2015) also replicated the emotional processing benefits for negative and especially for positive words while controlling for word frequency rather than manipulating it. Moreover, they reported emotion effects in eye tracking measures associated with later processing stages. For both positive and negative words, they observed shorter and fewer fixations compared to neutral words in early (e. g., first fixation duration) and late measures on the target word (e. g., second pass reading time) and on the post-target region. However, the study by Knickerbocker et al. allowed no direct comparison of positive and negative words because both were presented in different experiments. Sheikh and Titone (2016) also observed the processing advantage for positive compared to neutral words (indicated by shorter first fixation durations and gaze durations) for reading in a second language. Moreover, Yan and Sommer (2015, 2019) demonstrated the processing benefit for emotional words for a logographic writing system using Chinese characters. Both studies demonstrate foveal effects as reported by Scott et al. (2012). In addition, significant parafoveal effects of emotional words on the processing of neutral target words were observed. As initially hypothesized by Hyönä and Häikiö (2005), Yan and Sommer (2015) observed longer durations on words preceding both positive words and frequent negative words compared to words preceding neutral ones. That such parafoveal effects for emotional words were observed for Chinese readers, but not for readers of an alphabetic language, is in line with recent results showing that Chinese readers make more efficient use of parafoveal preprocessing as the Chinese writing system is in general more densely packed than alphabetic languages (Vasilev & Angele, 2017).

A recent study by Lüdtke and colleagues (submitted) using short textoids instead of single sentences further explored the effects of emotional word meaning on different stages of processing. The short textoids consisted of two sentences, the first containing a negative, a neutral, or a positive adjective followed by a noun, the second containing a pronominal anaphora referring back to the adjective-noun combination of the first sentence. Focusing on the processing of the adjectives, shorter first fixation and gaze durations were observed for positive compared to negative adjectives. Shorter gaze durations were observed for positive compared to neutral adjectives. A significant difference was also observed for negative compared to neutral adjectives. In contrast to Knickerbocker

et al. (2015), Lüdtke and colleagues observed more rereading for positive compared to neutral adjectives. While replicating the emotional processing benefit during early processing stages, especially for positive words in single sentence studies, these authors observed additional processing time for rereading positive words. Whether this is due to the resolution of co-referring pronouns or a general effect associated with the importance of emotional information has to be tested in future studies.

Taken together, the few eye tracking studies manipulating the emotional meaning of single words embedded in sentences replicate the effects observed in studies of single word recognition. All studies used well controlled stimuli, some also varied additional lexico-semantic features, and all used normal reading for comprehension as the main task. The results indicate that emotional words are more likely to attract readers' attention, resulting in an early processing benefit, especially for positive words. When the emotional word meaning was important for the meaning of the whole sentence, prolonged processing especially in measures associated with later stages of meaning integration and reinterpretation could be observed. This pattern suggests that the emotional processing benefit observed at the single word level can be accumulated at the text level (for positive evidence see Usée et al., 2020).

The Role of Emotions in Reading Paragraphs and Texts

Readers' reactions to different types of text content have been of interest since the early days of eye movement research. For example, Seibert (1943) examined 8th grade students' eye movements during reading of different types of texts: mathematics, biography, adventure, physical science, and geography. In comparison to other text types, adventure texts attracted more fixations and regressions, resulting in slower reading (as measured by words per minute). Because no direct measure of readers' emotional responses to texts were reported, these results speak only indirectly to the role of emotions in reading. Still, it is probably fair to speculate that adventure texts are more suspenseful or interesting to 8th grade readers than mathematics texts, suggesting that readers' emotions do play a role in the reading process.

However, since Seibert's day, very little research has systematically examined how reader emotions influence eye movement behavior during reading. The few studies fall into roughly two categories: studies that have manipulated

the valence of the reading materials, without paying attention to emotional reader responses, and studies that manipulated the emotional reaction of the reader by presenting text materials that can be expected to induce or provoke emotion. In the first category, an eye tracking study by Fang et al. (2018) examined the reading of positive ("My life is interesting"), negative ("I am a born loser") and neutral ("My table has four legs") sentences while the amount of text visible at a given time was manipulated in a so-called moving window paradigm. Looking at their data in the normal reading condition, it seems that there are no differences in total fixation time between sentence types. However, because the purpose of the study was to examine individual differences in attentional spans and not to directly compare reading times for different sentence types, no information about the lexical or syntactic qualities of different sentence types was given. These factors are known to influence eye movements during reading, complicating the interpretation of the comparisons between sentence types. Thus, the result is far from conclusive. In another study, Ballenghein and colleagues (2019) used eye tracking in combination with postural movement recordings to study reading of positive, negative, and neutral passages. They found that mean fixation durations were shorter during reading of positive than during reading of neutral texts, whereas there were no differences in the number of fixations, leading to shorter total fixation time on positive than on neutral texts. However, these results are also hard to interpret because different texts seemed to vary greatly in length, and no information about the lexical qualities or syntactic complexity of the texts was provided. The observed differences between positive and neutral texts could thus be due to multiple features other than valence.

In the second category, some studies have specifically targeted certain positive (e. g., amusement, interest) or negative (e. g., fear, jealousy) emotional reactions during reading and investigated their effects on eye movements. Studies that have examined processing of jokes indicate that amusement may facilitate processing (Ferstl et al., 2017; Mitchell et al., 2010). Coulson and colleagues (2006) first examined reader's eye movements during reading of jokes consisting of a single sentence. The last word of the sentence defined the sentence either as a joke or as a conventional (non-funny) sentence. Coulson and colleagues found that while there were no differences in first-pass reading times on the last (critical) word, readers were more likely to regress back to the earlier parts of joke sentences. However, it should be noted that the jokes used in the study were akin to garden-path sentences, in which the last word requires the reader to reassess the initial interpretation of the sentence. It is thus difficult to know whether the extra processing initiated from the last word was related to re-analyzing the meaning of the sentence, the experienced amusement, or a

combination of the two. In a study using short stories that contained a dialogue that either ended with a joke punchline or a non-funny ending, Mitchell and colleagues (2010) found that humorous content facilitated processing: readers spent longer fixation time on non-funny endings than on joke punchlines. In a well controlled study by Ferstl et al. (2017), participants were asked to rate either the funniness or comprehension difficulty of similar stories used by Mitchell et al. (2010). The results showed that total reading times were shorter for funny texts. A closer analysis of the eye movements on different parts of text (context and the joke punchline) showed that readers spent less time rereading the context in funny than in other texts. As for the punchline, there were no specific emotion-related effects on first-pass reading times, except for a slightly greater sentence wrap-up effect. The effects on punchline appeared in total reading time, reflecting that rereading times were shorter for punchlines in jokes than in other types of texts. Regressions within punchlines as well as regressions from the punchline back to the context were less likely in jokes than in other texts. These results suggest that a positive emotion, amusement, can facilitate text processing by reducing the likelihood of regressions and rereading. Ferstl et al. proposed that the experience of amusement when we understand a joke serves as a signal that we have understood it. There is thus no need to go back and check the interpretation as when reading non-funny texts.

On the other hand, positive affect is not always related to facilitation in processing, as indexed by shorter eye fixation times. A recent study on the influence of reader interest on eye movements during reading of an expository text showed that interested readers who reported using deep-level processing strategies did more rereading of the key elements (rather than details) of the text (Catrysse et al., 2018). In this case, a positive feeling towards the text increased the processing time spent on important segments.

Regarding the impact of negative emotions such as fear on eye movements during reading, the evidence is sparse. Warren and Jones (1943) manipulated fear by asking participants, some of whom had fear of heights, to read "dramatic descriptions of steeple jacks, riveters, and others working on high places and the dangers involved." An exciting story with no reference to high places was used as a control text. In order to maximize the manipulation of fear, participants read one of the fear-inducing texts "while sitting in an armless chair attached to the outer edge of a fourth-story window ledge." The standard measures of eye movements (number of fixations, duration of fixations, number of regressions) showed surprisingly little differences between participants who had fear of heights and those who did not during reading of the fear-inducing texts. However, when the authors looked closer at the scanpaths during reading

of different texts, participants who had fear of heights demonstrated deviating patterns of eye movements from normal reading: it seemed that especially when encountering parts of text that graphically described scary situations and especially when reading in a precarious place, their fixations were "wandering" or "curved." Unfortunately, this study only involved few participants, and, at the time, the authors had no way of quantifying the qualitative differences observed in readers' scanpaths in response to the fear-inducing conditions.

The influence of reader arousal on processing and comprehension of text was examined in a recent study by Mason and colleagues (2020). They presented participants multiple expository texts that included contradictory information about genetically manipulated food. Skin conductance level was used as a measure of arousal during reading, and comprehension of the text materials was checked with an essay writing task. The results showed that the correlation between arousal and eye movement measures was weak: a weak positive correlation (r=.15) was observed for first-pass fixation duration and a weak negative correlation (r=-.19) for look-back duration. Higher arousal and longer first-pass fixation times on sentences were related to poorer comprehension, indicating that arousal is not necessarily beneficial for comprehension. However, the relationship between arousal and comprehension depended on prior knowledge of the topic: for readers with more prior knowledge high arousal was associated with better comprehension.

A recent study by Mak and Willems (2018) indicated that emotional responses during reading modulate other processes during comprehension. Analyzing the eye tracking data of 102 subjects reading different literary short stories, the authors showed that the effect of different kinds of mental simulation, like perceptual and motor simulation, on gaze durations was modulated by self-reported emotional responses. Readers who rated the stories as sad, deeply moving, and suspenseful showed a stronger relationship between simulation and gaze duration. These readers read motor descriptions faster and perceptual content slower compared to readers with lower ratings. Although, the mechanisms underlying these relations are still unclear, the results suggest that emotions induced by the text had an influence on text comprehension processes evident especially in gaze duration.

Finally, it is noteworthy that readers may react to emotional texts in different ways. In a study examining sex differences in jealousy, Dunn and McLean (2015) asked participants to imagine themselves in a relationship and finding emotional messages on their partner's mobile phone. Eye movements were recorded to see how participants viewed messages containing either romantic or explicitly sexual content. Dunn and McLean found that males made more and

longer fixations on sexual than on romantic messages, whereas females made more and longer fixations on romantic messages.

In summary, very few studies have analyzed eye movements to study reading of texts that are likely to induce emotional responses. The results of these studies suggest that it is important to consider the type of text being read. A positive emotion, as when reading a positively valenced story (Ballenghein et al., 2019) or when being amused by jokes presented in dialogues (Ferstl et al., 2017; Mitchell et al., 2010), seems to facilitate processing. However, when reading an expository text, positive emotion might have a different effect: interest in text topic slowed down processing of key elements in the text (Catrysse et al., 2018). Moreover, there are individual differences between groups of readers in how they react to emotion-provoking texts (Dunn & McLean, 2015) which can also influence processes related to text comprehension (Mak & Willems, 2018; Mason et al., 2020).

Challenges When Examining Emotion Effects with Longer Text Materials

There are three problems with previous studies of reading paragraphs and longer texts. First, while some studies have adopted an experimental approach and used carefully controlled text materials (i. e., textoids), others have used more naturalistic texts. Unfortunately, in some of the latter, very little, if any, information about the nature or quality of the materials was provided, making it impossible to disentangle potential effects of lexical or syntactic features from those caused by emotional ones. It is indeed hard, if not impossible, to control for all possible lexical or syntactic factors while manipulating the emotional content of a text, especially when using longer and naturalistic literary materials. However, a possible solution to this dilemma is to apply state-of-the-art quantitative narrative analysis and sentiment analysis tools to a careful exploration of the text features and use predictive modeling to examine which features contributed to emotional responses (Jacobs, 2019; Jacobs & Kinder, 2019) and changes in eye movement patterns (Xue et al., 2019, 2020). Second, only a few studies measured the actual emotional reaction of readers. The others simply assumed that texts whose emotional features were rated by a separate sample of participants would induce a similar reaction in all readers. However, it is clear that there is individual variability in how readers react to emotional text information (e. g., Dunn & McLean, 2015) and that reader's disposition towards

a text makes a big difference in how the text is inspected (Catrysse et al., 2018). Third, very little attention has been paid to the reading task itself. Most studies have used the standard "read the text for comprehension" instruction with participants responding to questions or producing free recall after reading. Some studies have asked participants to rate the valence of the text materials, thus focusing the readers' attention specifically on the emotional content. Others do not even report what the participants' task was. Different task instructions, including the type of questions the reader has to respond to, make different types of information salient to the reader, and there might be interactions between task effects and those due to text characteristics (e. g., Ferstl et al., 2017). Thus, more attention should be paid to the kind of instructions given to the readers and how they may impact processing.

In sum, previous research on the role of emotions during reading of sentences and texts is sparse and mainly inconclusive with regard to the question of how emotion effects materialize in readers' eye movements. More careful consideration of the tasks, reader reactions, and (especially) the text materials is needed.

Future Directions

Use of Naturalistic Texts

> Should cognitive scientists and neuroscientists care about Dostoyevsky? (Willems & Jacobs, 2016, p. 243)
> We believe that the scientific study of narrative comprehension will move from using short, laboratory-contrived 'textoids' to longer naturalistic narratives (Bailey & Zacks, 2011, p. 72)

These quotes from two papers dealing with the scientific study of reading natural texts open the door to future developments. Indeed, the overwhelming majority of studies on eye movements in reading have dealt with textoids and also have completely neglected emotional aspects of reading. However, to paraphrase Jacobs et al. (2015), reading is not only cold information processing, but also involves "hot" affective and aesthetic processes that go far beyond what current models of word recognition, sentence processing, or text comprehension can explain. More ecologically valid (experimental) designs using natural texts like short stories (Ballenghein et al., 2019; Mak & Willems, 2018), poems (Xue et al., 2019, 2020) or excerpts from entire novels (Cop et al., 2017; Magyari

et al., 2020) should produce results which are more easily generalizable to everyday reading situations (Kandylaki & Bornkessel-Schlesewsky, 2019).

Use of natural text materials, whether they are expository or poetic pieces, no longer presents the challenges faced by researchers a decade or so ago. The public availability of text corpora, software for automated text analyses, or internet-based tools for collecting data has changed our possibilities enormously. As an example from the Neurocognitve Poetics perspective (Jacobs, 2015b; Willems & Jacobs, 2016), the entire corpus of 154 Shakespeare sonnets is now available together with a table specifying > 100 text features at all levels of analysis including "cognitive" features such as average word length or surprisal and affective semantic features like valence or arousal (Jacobs et al., 2017). Based on their quantitative narrative analysis of all Shakespeare sonnets, the authors also included easily testable predictions regarding eye movement behavior when reading a sonnet, and recent studies tested some of them (Xue et al., 2019, 2020). Still, it is obvious that, when trying to interpret eye tracking data collected during the reading of a sonnet or entire pages from a novel, things are a bit more complicated than in a typical 2x2 design investigating the effects of, say, word length and frequency on mean fixation durations during the reading of single isolated (i. e., context-free) sentences. While the seemingly uncountable number of intervening variables may appear discouraging, recent advances in machine learning assisted text and data analyses promise to overcome this problem. Of course, standard GLM accounts assuming linear relationships and the specification of interactions among independent variables in advance are of limited use in this context. What is needed is adaptable fitting of dependent variables (DVs) to independent variables (IVs) that adequately describe their complex nonlinear relationships. Current computational modeling techniques use neural networks and other machine learning tools that offer effective solutions for this problem, as pointed out in the next section. (e. g., Jacobs & Kinder, 2017; Jacobs & Lüdtke, 2017; Xue et al., 2019).

Advanced Exploratory, Predictive, and Explanatory Computational Methods and Models

> We propose that principles and techniques from the field of machine learning can help psychology become a more predictive science. (Yarkoni & Westfall, 2017, p. 1100).

The paper featuring the above citation argues for a major change in psychological research, away from tightly controlled experiments aiming at statistically significant ("causal") effects of two or three IVs on one or two DVs (at the purely

conventional level of $p = .05$) and towards predictive modeling of the interactive effects of a large number of predictors on multiple DVs. Whereas the standard 2x2 ANOVA designs in experimental psychology and eye movements in reading research maximize chances to obtain a p-value of .05 (what Yarkoni & Westfall call "p-hacking"), the alternative perspective attempts to maximize variance accounted for in the DVs. In the field of machine learning, one aims at predicting future observations as accurately as possible (i. e., minimizing prediction error). This can be done "categorically" via so-called classifiers or "continuously" via regressors.

Recent examples for successfully applying this novel research strategy include:

- The prediction of immersiveness ratings regarding passages from E. T. A. Hoffmann's classical text *The Sandman* (Jacobs & Lüdtke, 2017): using a simple neural net (multilayer perceptron), the authors obtained a (regressor) prediction accuracy of about 60% (R^2 for the test set)
- The prediction of word beauty ratings (Jacobs, 2017): using a very powerful classifier called Extremely Randomized Trees/ERT (Geurts et al., 2006), the achieved prediction accuracy was .99.
- The prediction of the aptness and literariness of poetic metaphors (Jacobs & Kinder, 2017, 2018): again using the potent ERT classifier, the authors obtained accuracies >.9.
- The prediction of eye movement parameters for readers reading Shakespeare sonnets (Xue et al., 2019, 2020): using a neural net regressor with seven predictors (surface features like word length or sonority score), the authors obtained prediction accuracies between .55 and .6 depending on the DV. In contrast, when running a standard GLM analysis, accuracies were much lower (.2-.3).
- The prediction of "joyful," "fearful," and "neutral" ratings for segments from the Harry Potter novels (e. g., Rowling, 1999): a novel sentiment analysis tool called *SentiArt* (see Sentiart.de) and multiple classifiers (e. g., neural net, naïve Bayes) achieved a maximum accuracy of >.9 (Jacobs, 2019; Jacobs & Kinder, 2019)

Based on the preceding examples, procedures in future studies of how emotional aspects of natural texts influence eye movements could involve two steps. In a first step, an exploratory, predictive modeling approach attempts to find the most important text features (out of a large collection generated via appropriate quantitative narrative analysis tools) for predicting a given eye movement parameter, e. g., first fixation or gaze duration. Once a limited number of such fea-

tures has been identified a second step could then experimentally test the (isolated) effects of these features in a standard ANOVA design.

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