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The Information Gathering Framework – a Cognitive Model of Regressive Eye Movements during Reading

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Increased fixation durations and a higher number of regressive eye movements are both interpreted as to reflect processing difficulties during reading. But in which contexts do the eyes just increase fixation time and in which contexts do they trigger a regressive eye movement? Based on the idea that the function of a regression is to gather additional information, a new cognitive model is proposed: The Information Gathering Framework (IGF). This model describes the interaction between fixation durations and regressive saccades by setting different thresholds for the so-called confidence level which cause a certain action.
In a first step, current models of eye movement control are reviewed before we describe the architecture of the framework in more detail. We then derive clear predictions from the model and test these predictions on data of a reading experiment conducted by Weiss et al. (2018). The results show clear evidence for two functionally distinguished types of regressive eye movements during reading as well as for the importance of the perceptual span for selecting the regression target.

Keywords: Eye movement, regressive saccades, reading, eye tracking, parafoveal processing, attention, models of eye movement control

Introduction

During reading the eyes do not smoothly move through the sentence but rather show an alternating pattern of fixations and saccadic eye movements. In 1980, Just and Carpenter proposed with their famous eye mind hypothesis that "the eye remains fixated on a word as long as the word is being processed" (Just & Carpenter, 1980, p. 330). Although it is now obvious that this claim was too strong (see e.g. the so called 'parafoveal on foveal effects', Kennedy, 2000), the eye mind hypothesis laid the basis for using eye movements during reading in order to examine mechanisms of language processing online. The rationale behind this research is that language and other processing difficulties cause 'costs'. In reading, these costs show up either in the form of longer fixation times or in the form of a higher number of so-called 'regressive saccades' which move the eyes against the intended reading direction. These regressive saccades occur frequently during normal reading, with approximately 5–20% of all saccades being regressions (Inhoff, Kim, & Radach, 2019). However, since in the literature both measures are interpreted as to reflect processing difficulties, this raises the important question in which contexts the eyes just increase fixation time and in which contexts they trigger a regressive eye movement.

Evidence for functional differences between regression rates and increased fixation durations comes from Altman and colleagues (Altmann, Garnham, & Dennis, 1992) who reported the counterintuitive finding that fixations preceding regressions tend to be shorter than fixations preceding progressions, which indicates that these two measures do not just 'sum-up' each other. Also, eye movements provide a physically different mechanism compared to increased fixation durations because they allow for the intake of additional information (information that often has been processed earlier, at least partly). Thus, as a first step we propose the working hypothesis that difficulties in language processing show up in the form of increased fixation times (first pass times) if the problem can be solved with the currently available information, and in the form of higher regression rates, if the problem cannot be solved with the currently available information.

Although both fixation times and regression rates have been well known in reading research for many decades, they received very different attention. We can summarize past research by saying that fixation times have been studied intensively: Hundreds of experiments have been conducted showing that fixation times are sensitive to lower-order language processing like frequency, word length and predictability but also to syntax and semantic processing (Rayner, 2009). There exists even an impressing number of computational reading models succeed in predicting and simulating human reading behavior (see, e.g., E-Z Reader: Reichle, Pollatsek, Fisher, & Rayner, 1998; or SWIFT: Engbert, Nuthmann, Richter, & Kliegl, 2005).

However, the picture with regard to regressive eye movements looks quite differently. Overall, only a small number of experiments has been carried out in order to explicitly examine regressions during reading (for a recent overview, see Inhoff et al., 2019). One reason might be that it is very hard to control regressions experimentally and to particularly predict their target position. However, it is known that a higher number of regressions can be attributed to difficulties in higher-order language processing (e.g. syntax, semantic and discourse processing; see again Rayner, 2009, for an overview) but that regressions also often show up at the end of a sentence (so-called 'sentence wrap-up effects', see e.g., Rayner, Kambe, & Duffy, 2000; Hirotani, Frazier, & Rayner, 2006). In addition, there are 'small regressions' that typically fall within a word or target the immediately preceding word and that are assumed to reflect targeting error (Inhoff et al., 2019).

Regressions in the context of current models of eye movements control

After first primarily focusing on low-level factors like frequency or word length and their interaction with eye movement behavior during reading, recent models of eye movement control were extended in order to capture higher-language processing as well. This also includes regressive eye movements. In the following, we will briefly discuss two influential models, namely the E-Z Reader 10 and the SWIFT model, with regard to regressive eye movements. After that we will turn to the to our knowledge only model that explicitly focuses on regressive eye movements during reading which is the model of Bicknell & Levy (2010)

E-Z Reader 10

The E-Z Reader model (Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2006) was first developed to account for the interplay between lexical processing, attention allocation, and saccadic programming during reading and made no predictions about higher level language processing. However, the latest version of the model, E-Z Reader 10 (Reichle et al., 2009), now also tries to explain the interaction between 'post-lexical processing' and eye movement control.

For this reason, a post-lexical integration step has been added to the model architecture. During this step, the currently processed word (word n) is integrated into higher-level representations like the syntactic structure or the discourse model. In case this integration fails, it causes both an attention shift and a regressive eye movement "back to the point at which the difficulty became evident (i.e., word n), as opposed to some earlier sentence location" (Reichle et al., 2009, p. 6).

However, the model can only account for regressions targeting word n and, in addition, only for postlexical integration difficulties, which is a simplification in both ways. On the one hand, regression target locations show a more complex distribution pattern (see e.g. Inhoff et al., 2019, for a review) and on the other hand, postlexical integration difficulties cannot account for all types of regressions (see e.g. the function of 'small regressions' proposed by Inhoff et al., 2019, or the so-called 'sentence wrap-up effects' mentioned earlier). But we have to keep in mind that the authors of the model explicitly state that "the integration stage […] is a placeholder for a deeper theory of postlexical language processing during reading. Our goal in including this stage is therefore quite modest: to provide a tentative account of how […] postlexical variables might affect readers' eye movements." (p. 6). In other words, the E-Z Reader 10 model is not designed to simulate the whole range of regressive eye movements during reading but provides only a limited but helpful tool in modelling eye movements during higher-order language processing.

SWIFT

The SWIFT model, proposed by Engbert and colleagues (Engbert, Longtin, & Kliegl, 2002; Engbert et al., 2005), is another highly advanced model of eye movement control. It assumes that multiple words are processed in parallel while saccades are generated autonomously, per default targeting the next word. This automatic saccade programming can be canceled if a new saccade is initiated during a first labile level of saccade programming (which happens, e.g., in skipping). Importantly, saccade programming and targeting is primarily driven by word recognition which influences the activation of potential saccade targets on a saliency map (the activation field). According to the minimalization approach of the SWIFT model, word recognition is the driving principle for all types of saccades which also includes regressive eye movements. This means that regressive eye movements are assumed to be triggered by incomplete word recognition. In this case, the eyes are re-directed to the word where the recognition failed.

As the E-Z Reader model, the SWIFT model does not claim to account for the full pattern of regressive eye movements during reading. Thus, we see again some limitations of the model with regard to regressions (and to word processing in general). As for the E-Z Reader model we find that the SWIFT model is restricted to regressions which target the immediately preceding word. However, the main problem of the model is related to the concept of incomplete word recognition, which raises the question if word recognition can ever be completed at all. Given the large amount of information that is connected to a word (e.g. its meaning, semantic neighborhood, word class as well as predictions about other entities in the sentence and so forth), it is very problematic to view word recognition as an 'all or nothing' task. Rather, it is more convincing to assume that word recognition is a process that needs time and can never be completed.

Falling confidence

Due to the limitations of the E-Z Reader and the SWIFT model with regard to regressive eye movements, Bicknell and Levy proposed another model of eye movement control that aims to overcome the weaknesses of the former models (Bicknell & Levy, 2010). We will refer to this model as the 'model of falling confidence' or 'FC model' for short. At the core, it is assumed that the word identification process is never completed. Thus, "it is possible that later parts of a sentence can cause a reader's confidence in the identity of the previous regions to fall" (Bicknell & Levy, 2010, p. 1170) which triggers a regressive eye movement in order to get more visual information about the previous region.

According to the framework, the model generates distributions over possible identities of the sentence, based on its language model. During a fixation, the noisy visual input is used to update the model's beliefs by a Bayesian likelihood term and by the language model. Thereupon, the model selects an action which could either be to continue fixating, to trigger a saccade or to stop reading the sentence before the cycle repeats.

A simple control policy is assumed to decide between actions, which works on the basis of two thresholds: The first value defines the threshold for a character to remain fixated. The second value defines the threshold for an (already processed) character on a leftward position to be fixated again (by a regression). Thus, the model allows to independently modulate the control policy with regards to processing depths (i.e., increased fixation durations) and regression probability which determines the speed and accuracy of the model. It is hypothesized that "for any given level of speed and accuracy achieved by a non-regressive policy, there is a faster and more accurate policy that makes a faster left-to-right pass but occasionally does make regressions." (Bicknell & Levy, 2010, p. 1174).

The model of Bicknell & Levy fits well with the working hypothesis proposed at the beginning of this paper and offers a clear mathematical description of how such an account can be integrated into a simulation model. Furthermore, it takes the basic ideas of the SWIFT model but replaces its problematic concept of "incomplete word recognition" by the idea that word identification never is completed. However, the major weakness of the model is that it has never been tested on human data. Bicknell and Levy took the model to simulate regression behavior on English sentences, but they just compared the efficiency of different reading strategies by adjusting the thresholds for the control policy and measured the resulting reading speed and accuracy in different simulations. Thus, it is completely unclear if the model is able to account for human reading behavior and if the assumptions of the model have any real-world reliability.

A new approach: The Information Gathering Framework

After having reviewed how current models of eye movement control try to capture regressive eye movements in reading, it becomes apparent that all of them add helpful ideas to our understanding of mechanisms that control regressive eye movements during reading but that they all have limitations in several ways as well.

In the following, we will therefore propose a new framework that may provide a general tool for our understanding of regressive eye movements, without limiting it to a small range of linguistic phenomena. As a starting point, we will use the FC model proposed by Bicknell and Levy (2010). But instead of focusing on theoretical considerations about reading strategies, the current aim is to develop a realistic model of human reading behavior, which means that the model should be able to cover findings from the existing literature as well as to make further testable predictions about reading behavior. This, however, requires some substantial modifications in the architecture of the FC model, so that we will call the new account the Information Gathering Framework (IGF).

With this approach we add a new perspective on the topic that may help us to better understand regressions during reading without declining approaches that have been already developed. We acknowledge that our approach has limitations in several ways as well and we want to encourage others to also test and modify this framework. Also note that in contrast to the FC model, the IGF is not incorporated into a computational model as yet that allows for simulating reading. Instead, the IGF takes into account more cognitive and linguistic properties of eye movement control than the former model does. But the current considerations should be used by future research to combine these two approaches and to develop a computational version of the IGF as well.

The architecture of the Information Gathering Framework

In the following we will discuss the main properties of the model and clarify its modifications from the FC model. Please notice that since Inhoff et al. (2019) argued that there exist two different types of regressions during reading (small vs. long regressions) which clearly differ with regard to their characteristics and functions, we will explicitly focus on inter-word regressions (long regressions) here. Thus, our model does not intend to make claims about 'small regressions' because they occur nearly without any correlation to language processing. It also should be mentioned that if we talk about 'fixations' we do not mean single fixations but in in fact first pass fixation times for a word.

(1) Information gathering as the unifying principle of regressive eye movements

In contrast to accounts that propose that regressions simply reflect some increased processing demands due to problems in the course of sentence interpretation (e.g., Mitchell et al., 2008), we argue that regressions are not merely a response but rather a solving mechanism to those problems (see also Schotter et al., 2014; Metzner et al., 2016). Thus, the eye movement itself has a function and the role of regressions in sentence interpretation is directly tied to this function.

Several reasons why a regression is launched have been discussed in the literature, e.g., difficulties in postlexical integration (Reichle et al., 2009), difficulties in word identification (Vitu & McConkie, 2000; Engbert et al., 2005) or difficulties in syntax / semantic processing (Frazier & Rayner, 1982). But crucially, none of these functions can account for all regressive eye movements occurring during sentence reading. However, because all regressions share the same characteristics (e.g., an eye movement against the intended reading direction, rereading of former sentence material, etc.), we claim that the function of a regression can be derived from the properties of the eye movement itself, which is to send the eye's fovea to a certain part earlier in the sentence, taking in additional visual input. Thus, the IGF proposes that the function of regressions is to gather additional information relevant in the course of sentence interpretation, more precisely, to gather additional information about the identity of words.

(2) The lexical quality level

The FC model proposes that because word identification is based on noisy visual information, "word recognition may be best thought of as a process that never is completed'" (Bicknell & Levy, 2010, p. 1170). Although we agree on the assumption of incomplete word recognition, we doubt that noisy visual information is in fact the major determinant of word identification, especially because there exists convincing evidence that the decoding of visual information occurs very rapidly (e.g., Ishida & Ikeda, 1989). Thus, we rather claim that word identification is mainly affected by the retrieval of the lexical information (as also proposed by the SWIFT and E-Z Reader model).

To incorporate this idea in our framework, we assume that the underlying language model contains lexical representations of each word. Specifically, the lexical representations stored in the memory have to be viewed as (theoretically) infinite bundles of features, containing information about the word's orthography, phonology, meaning, morpho-syntax as well as its constituent binding preferences (c.f. also Perfetti, 2007, who introduced this idea as the concept of lexical quality in order to explain differences in language skill between individuals). Because of the complexity of the lexical representation it takes time to retrieve this information from the lexicon.

We refer to the amount of information about a word that is currently retrieved from the lexicon with the term 'lexical quality level'. Typically, the amount of information (and thus the lexical quality level) continuously increases during a fixation, because a fixation allows for the retrieval of lexical information on the basis of the visual input. However, once the eyes have moved to the next word, no additional information can be received and the quality level is then continuously decreasing over time due to interference from other words and due to a decay of the memory trace (Lewis & Vasishth, 2005; see Figure 1 for a schematic illustration). Also note that the lexical quality level of a word (as the confidence level, see below) is never reaching the full quality level because the retrieval of the information from the lexical entry can by definition never be completed.

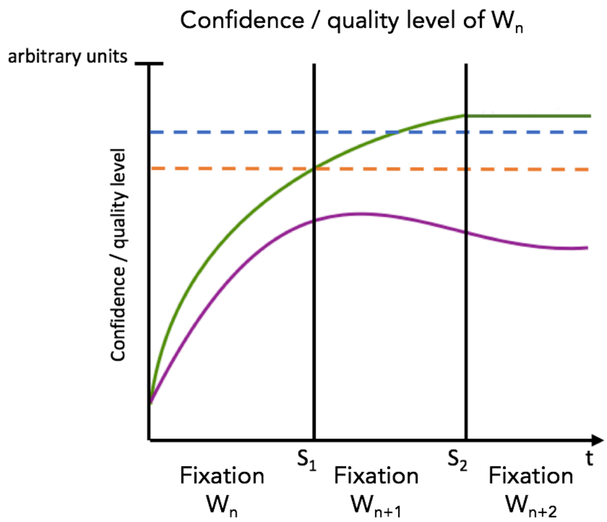

Figure 1: Schematic illustration of the confidence / quality level of a single word during a typical sequence of two progressive saccades: Whereas the confidence level is continuously increasing and asymptotically approaching the full confidence level, the quality level decreases due to interference and decay after the eyes moved to the next word. Legend: green = confidence level, purple = lexical quality level, orange = forward threshold, blue = backward threshold, S1 = saccade to word n+1, S2 = saccade to word n+2, t = time.

(3) The confidence level

In addition to the lexical quality level, the IFG claims that a confidence level for each word is computed which basically represents the reader's confidence into the identity of the current word. According to the FC model, the reader computes a confidence level of a particular word on the basis of its language model. If additional information causes the confidence into a previous word's identity to fall under a certain threshold, a regressive saccade to this particular word is triggered. Because the FC model computes the confidence level on the basis of the underlying bigram frequency model, its focus is set on reducing noisy visual input and the computation of confidence levels is not viewed as a matter of language processing.

Since this is a very unrealistic assumption, we propose within the IFG that the computation of confidence levels (as with the computation of the lexical quality levels) is based on linguistic processing and takes a certain amount of time. During this time, the confidence level of a word typically increases (asymptotically approaching but never reaching the full confidence level), because more supporting evidence is given from the information of the lexical representation (see Figure 1 for a schematic illustration). For the current purpose, it is assumed that the confidence level is computed by matching the features of the lexical representation with the predictions of former sentence material on the basis of explicit production rules (Newell, 1973). These production rules represent all procedural knowledge (grammatical knowledge) and set condition–action pairs. For example, if an inanimate noun (e.g. *the table*) is encountered as the initial argument in an English sentence (condition), the production rules predict that a verb (action) will follow in the course of the sentence. More precisely, they predict that this verb should agree with the argument in number (singular), comes with an inanimate subject, and so on. If a verb like *talks* is encountered next, this leads to a violation of production rules because *talks* requires an animate subject. On the other hand, if a pronoun like the word *which* is following, it induces a relative clause. In this case, the production rules are not violated and the action (the expected verb) is simply postponed. Also, not every condition-action pair is mandatory; some pairs are just optional (e.g., the indirect object of verbs like write: *He writes a letter (to his father)*). If the evidence provided by the lexical representation matches the predictions made on the basis of the production rules, a high confidence level is computed. If the production rules are violated by contrast, it leads to a low confidence level. Accordingly, if the context is highly predictive, less lexical information and thus less time is needed to reach a certain level of confidence which results in shorter fixation durations.

Note that the level of confidence is highly correlated to the lexical quality level, but these two parameters are not the same. A poor reader could have a high confidence in a word's identity although it is ambiguous (e.g., in meaning). But due to a small lexicon which implies a representation of a few features only, the reader is not aware of these alternative interpretations. Accordingly, a proficient reader could have low confidence in the same word's identity because he takes into account several potential ambiguities that the poor reader is not aware of. In addition, a highly predictive context may also affect that less information (and thus a lower lexical quality level) is needed to confirm this prediction and a certain level of confidence is reached. This explains why fixations on highly predictive words are shorter than those on unpredictable words (e.g., Balota, Pollatsek, & Rayner, 1985).

(4) The confidence level is monitored by two independent control mechanisms

The FC model proposes that the generation of eye movements is monitored by a simple control policy that sets two different values of confidence that cause an action. If the first value is reached, a forward saccade to the next word of low confidence is initiated. If the confidence level of a word falls under the second value, a regressive eye movement to this particular word is triggered.

In the IFG the actions are also controlled by two independent thresholds for the confidence level, which we refer to as the forward and the backward threshold, respectively (see Figure 1).

The first (forward) mechanism defines the level of first pass confidence, namely the amount of evidence about word n's identity that is retrieved in first pass reading and assessed to be sufficient for the current sentence interpretation. When a certain level of confidence is reached, the eyes move to the next word.

It is further proposed that this forward control mechanism works in a highly automatic manner, per default targeting the next word. This automatic saccade generation is canceled and the eyes move to word n+2, if parafoveal processing already reveals a certain level of confidence for word n+1. The forward control mechanism proposed here is compatible with current models of saccade control like SWIFT (Engbert et al., 2002; Engbert et al., 2005) that assume a) parallel processing of different words, b) largely automatic generation of progressive eye movements, and c) word identification as the core function of saccades in reading.

This forward threshold in particular mediates between speed and accuracy: If the threshold is set down, the reading speed is increased but accuracy also suffers. If the threshold is set high, by contrast, the accuracy is higher but at the expense of reduced reading speed.

The second (backward) mechanism defines the level of confidence that has to be reached in order to prevent a regressive eye movement from happening. Thus, a regression is performed whenever the level of confidence for a word does not reach a certain threshold. In contrast to the forward control mechanism, this backward mechanism is highly linguistically controlled.

In addition, the backward mechanism further monitors the selection of regression targets by shifting the attention to the left and by re-computing the confidence levels of previous words, more precisely of words within the perceptual span. If the re-computing reveals that the confidence level of one word falls under the backward threshold, a regression to this particular word is performed. If it is the case that the confidence level of more than one word or no words falls under the backward threshold, the regression target is selected by using experience-based strategies (we will explain this procedure in more detail below).

Although the forward and backward control mechanisms often interact, they are assumed to be independent and may be adjusted separately. Thus, there may exist a first pass strategy that allows for relatively superficial reading, but this does not necessarily mean that at the same time the probability for regressions increases. In addition, both control mechanisms are assumed to be sensitive to top-down influences i.e. tasks that may reduce or increase the thresholds for first pass reading times and regressions. Bicknell & Levy (2010) for example showed that the most efficient reading strategy (i.e., the one that leads to highest comprehension accuracy) is one that allows for a lower level of confidence in first pass and increases the probability for regressions at the same time.

(5) Limited focus of attention

The FC model takes into account the limitations of the visual field in order to compute the degree of noisiness for the visual input, but it is not specified with regard to the focus of attention. However, because the underlying language model is restricted to bigram frequencies, the confidence level of a word can only be affected by the visual information about the subsequent word.

Within the IGF, the visual field also shapes the amount of visual information that is available to the reader during a fixation and that is used for the computation of the lexical quality level. But in addition, it is assumed that the computation of confidence levels always requires attention, so that not the confidence levels of all words in a sentence can be monitored in parallel. In particular, research on the basis of SAT (speed accuracy trade-off) experiments has indicated that the focus of attention is very limited, covering only two chunks (McElree, 2006). We therefore assume within the IGF that the focus of attention is restricted to the word of the current fixation (W_6 in the example below) and the word before (W_5 in the example below) which means that only the lexical representations of these two words can be used in parallel to compute the confidence levels (see Figure 2).

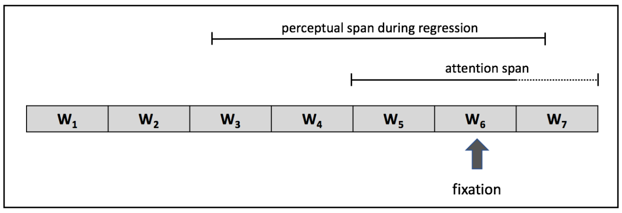

Figure 2: Schematic illustration of the attention and perceptual span. Only word representations within the attention span can be used to compute confidence levels during the current fixation. If a regression is triggered on W_6, the attention shifts and the lexical representations of the words within the perceptual span (here W_3, W_4 and W_5, assuming 5 letter words) can be retrieved and used for a new computation of confidence levels. If this computation reveals no clear result, a regression target is selected on the basis of strategy. Note that if W_1 or W_2 becomes the target of a regression, these words are always assumed to be selected on the basis of a strategy because they are beyond the perceptual span. See text for further details.

If a regression is triggered on W_6, however, an attention shift to the left is performed that allows for the retrieval of previous lexical representations and a re-computation of confidence levels. This assumption follows from research on the perceptual span in reading, which describes the area around the current fixation where disruptions of the text still affect reading speed (see Rayner, 2014, for a recent review).

Several studies have shown that the perceptual span comprises 3 to 4 letter spaces to the left of the fixation (McConkie & Rayner, 1976; Rayner, Well, & Pollatsek, 1980) and 14 to 15 letter spaces to the right of the fixation during reading (McConkie & Rayner, 1975; Rayner & Bertera, 1979). Because the perceptual span is not a restriction of the visual system per se, but is rather affected by attentional processes (for example indicated by the finding that systematically increasing the font size of the letters to the right or left of the fixation does not reduce the perceptual span: Miellet, O’Donnell, & Sereno, 2009), it has been hypothesized that the perceptual span changes when making a regressive eye movement. This hypothesis has been confirmed by research of Apel and colleagues (Apel, Henderson, & Ferreira, 2012), who showed that the size of the perceptual span switches toward the direction of the eye movement which also implies a shift of attention to the left. Although the authors did not answer the question of the actual size of the perceptual span to the left of a fixation during regressions (and of course more research is needed), we assume for our purposes that it encompasses 15 characters to the left, according to the size of the right perceptual span in progressive eye movements.

It follows that for the architecture of our IGF, when making a regression, the lexical representations of the words within 15 characters to the left of a regression can be used to re-compute the confidence levels and to guide the regression target selection (see section below).

(6) Four different eye movement scenarios

In a framework with an architecture described above, four different eye movement scenarios are possible (see Figure 3). We will now describe them in turn. Note that each graph represents the confidence level of six words (W_1–W_6) while the eyes are currently fixating word 6 (W_6).

Pattern 1

The confidence level of W_5 has already passed the forward threshold which triggered a saccade to W_6. Now the confidence level of W_6 is also increasing and the word remains fixated until the confidence level of W_6 reaches the forward threshold or the confidence level of W_5 drops under the forward threshold.

Pattern 2

The confidence level of W_5 drops under the forward threshold after first passing it (which triggered the saccade to W_6). This may happen because the computation of the confidence level for W_5 still continues after the eyes moved to W_6. Sometimes the computation of the confidence levels reveals that W_5 cannot be integrated into the current sentence structure which causes that the confidence level of W_5 drops under the forward threshold. As a response, a regressive eye movement is triggered.

Pattern 3

There is another scenario that causes a regression: If the confidence level of W_6 already passed the forward threshold but the confidence level of W_5 did not reach the backward threshold. This happens for example if the new input does not provide the expected evidence about W_5's identity. In this case, the confidence level increases only slowly. As the confidence level of W_6 already reached the forward threshold, a regression is triggered. We assume that this happens especially at the end of a sentence where the whole sentence structure is evaluated.

Pattern 4

In this case, the confidence level of W_6 reached the forward threshold after the confidence level of W_5 reached the backward threshold. This is assumed to be the "normal" case and it triggers an eye movement to W_7.

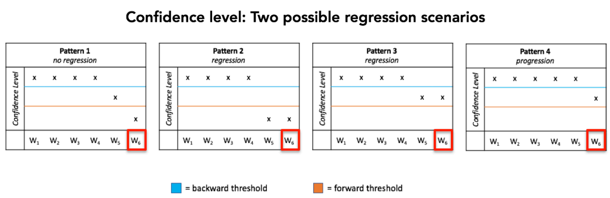

Figure 3: Potential patterns of confidence levels. Each pattern represents the confidence levels of six words (W_1 to W_6) during a fixation on W_6. Please note that only the confidence levels of two words (W_5 and W_6 in this example) can be computed in parallel.

(7) How the target of a regressive eye movement is selected

The IGF predicts that there are two different regression scenarios: Regressions due to integration difficulties (Pattern 2) on the one hand and regressions due to missing evidence on the other (Pattern 3). However, a crucial question is how the target of this regressive eye movement is selected.

The FC model predicts that the regression always targets the word with the confidence level under the backward threshold which is always the directly preceding word (due to the underlying bigram frequency model). However, the assumption that regressions are always targeting word n-1 (an assumption which is also shared by the E-Z Reader 10 model, for example) is just a simplified approximation, as discussed above. We also have to keep in mind that the word in the sentence where problems become apparent does not always correspond to the word that causes difficulties. A very prominent example are garden path sentences where difficulties are often caused by a misinterpretation of a word earlier in the sentence. In this case, a re-inspection of the word n-1 would not help to solve the problem and since we assume that the function of a regression is to solve the problem, this is not a plausible mechanism.

Another opportunity would be to select the word with the lowest quality level as the target for the regression instead because there is an increased likelihood that more evidence (provided by the lexical representation) about this word would help to increase confidence. However, there are also difficulties with this assumption: As already discussed, the quality level and the confidence level are not the same. Thus, a low quality level does not automatically cause a low confidence level. In addition, this assumption would lead to the conclusion that words earlier in the sentence / text are more likely to become the target of a regression because the quality level is low (due to the decrease over time). This prediction, however, is not supported by the empirical findings either.

Thus, we assume that in the case of a regression a re-computation of the confidence levels of previous words takes place and that the selection of a regression target is linguistically constrained. In particular, it is assumed that if a regression is triggered, the attention is shifted to the left of the fixation and the confidence levels of the words within the perceptual span (14-15 characters) are computed again, on the basis of their lexical representation and the applied production rules. If this causes the confidence level of a particular word (in our example of Figure 2 the confidence level of W_3, W_4 or W_5, given 5 letter words) to fall under the backward threshold, this word is selected as the regression target.

In the case the confidence of more than one word falls under the backward threshold, the target (W_3, W_4 or W_5) is selected by the backward control mechanism on the basis of experience-based strategies. The same happens if none of the words' confidence levels within the perceptional span falls under the backward threshold. In this case, the confidence levels of all words in a sentence fall under the backward threshold (as some kind of 'chaos response' because the cause of the problem cannot be determined by the reader) and the backward control mechanism selects the regression target on the basis of a limited set of strategies. Note that it is likely that a target selection based on strategy is more the rule than an exception.

The limited set of selection strategies is based on language experience and aims to define the most efficient way to gather the required information, without taking into account the details of the lexical representation itself. Most efficient is defined as the combination of speed and accuracy, which means that the strategy is the fastest way to find the most relevant information in the absence of explicit knowledge, taking into account the speed-accuracy tradeoff. Limited set means that only a restricted number of strategies (maybe 3-5) and not a full variety of strategies exist. Language experience means that this strategy has been applied most frequently in the past and yielded good results, so that the reader when he is faced with a certain category of tasks, assesses the likelihood where the relevant information can be found on the basis of his language experience. Strategy means that the same type of eye movement (B) is performed when faced with the same task (A) – at least for a single reader – resulting in the simple condition term: if A, then B.

Note that the landing site patterns of regressions reported in the literature (e.g., Frazier & Rayner, 1982; Mitchell et al., 2008; Meseguer et al., 2002; von der Malsburg & Vasishth, 2011, 2013) show a distribution that challenges the assumptions of such a strong linguistic guidance. But whereas factors other than linguistic properties have rarely been discussed in the context of regression landing sites, we think that more factors may shape the landing site distribution, although linguistic computations are assumed to be the main determinant. These factors are differences between individuals with regard to linguistic knowledge (e.g., Wells, Christiansen, Race, Acheson, & Macdonald, 2009) or memory capacities (Baddeley, 2003; Van Dyke & Johns, 2012). But also general factors like spatial memory (Inhoff & Weger, 2005; Weger & Inhoff, 2007), oculomotor error (McConkie, Kerr, Reddix, & Zola, 1988) and visual salience (e.g., Friston, Adams, Perrinet, & Breakspear, 2012) may play an important role in determining landing site distributions of regressions. This, of course, makes it hard to draw strong predictions from the model architecture and we acknowledge that more research has to be done in this field.

Applying the Information Gathering Framework to the findings in the literature

Having described the main properties of the IGF we will now discuss how the model may account for a variety of critical empirical findings reported in the context of regressive eye movements during reading.

(1) Regressions to the immediately preceding word

Although the landing positions of regressions are spread over the whole sentence, the majority of regressive eye movements targets the word immediately preceding the currently fixated word (see e.g., Vitu & McConkie, 2000; von der Malsburg & Vasishth, 2011, 2013, for corresponding evidence). In particular, all current models of eye movement control discussed above (E-Z Reader 10, SWIFT, Model of falling confidence) only account for those instances.

Mitchell et al. (2008) argue (in favor of an automatic regression mechanism) that a regression from word n+1 to word n is the "smallest possible regression" (p. 271). And of course, a regression to word n has some important advantages compared to target words that are farther away from the current fixation: First, the saccade is short and fast, so that less effort for its execution and control is necessary. Second, the target word can be processed parafoveally so that the saccade can be guided by using visual input. Third, memory demands are low because the word has been encountered immediately before.

In the IGF, however, we argue that regressions to the immediately preceding word can be explained more plausibly by a regression mechanism that is controlled by linguistic factors.

As already discussed, the IGF assumes that the computation of the confidence level continues after the eyes have moved to word n+1 because the retrieval and integration of linguistic information takes time – an assumption that is in accordance with reading models like E-Z Reader and SWIFT (c.f. also the so-called 'spill-over effects': Rayner & Duffy, 1986; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). In particular, because language processing is hierarchically organized and this hierarchy is assumed to correspond to the time course of sentence interpretation (at least to some degree), the computation of the confidence level of word n on word n+1 encompasses primarily higher-order linguistic processing like lexical integration. Thus, an integration failure of word n will often become apparent only on word n+1 (see Pattern 2 described above). If this integration fails because the predictions based on the production rules are not met, a regression is triggered. If the production rules reveal that more information about word n is needed (which is of course within the perceptual span and thus subject to linguistically based re-computation of confidence levels), the confidence level of word n is set down and a regression is performed (because the eyes already have moved to word n+1), targeting word n (see also Reichle et al., 2009).

Because there are many more instances in which the integration of word n fails due to wrong / less specified assumptions about its identity than instances where the integration fails due to wrong / less specified identities of previous words (which is the case for instance in most garden path sentences), the eyes very frequently regress to word n. This explains why the majority of regressions targets the immediately preceding word.

In addition, the backward control mechanism could also have developed a strategy that selects the preceding word. Recall that the strategies applied by the backward control mechanism are assumed to be based on general language knowledge / experience and hence operate on frequency. Thus, in the case a low confidence level of more than one word (or no words) is computed, the backward control mechanism might select the preceding word, because this word often provides the most useful information in order to solve the processing problem.

This view is further supported by the findings of von der Malsburg & Vasishth (2013) that indicate that low-capacity readers were less likely to reread the sentences when faced with garden path sentences. Instead, they used rapid regressions to the word in the pre-disambiguating region more frequently. Since these rapid regressions provide some advantages with regard to memory capacities (as discussed above), this strategy suits readers with low memory capacities.

(2) Properties of the target word

In their analysis of an eye tracking corpus of four adult readers, Vitu & McConkie (2000) reported two relevant findings with regard to regressive eye movements: First, if a word has been skipped, the probability increases that this word becomes a target of a regression. Second, if a word is long and low in frequency, the probability also increases that this word becomes a target of a regression. We will now briefly discuss how the IGF may account for these results.

If a word is processed only parafoveally, the amount of information that can be retrieved from the visual input is reduced. The same applies for words that are very long or low in frequency which also delays the retrieval of word information (Forster & Chambers, 1973; Weekes, 1997). In the current framework, this reduced information leads to a lower level of lexical quality, albeit that the confidence level reaches the forward threshold. Thus, if input later in the sentence reveals some difficulties that cause the confidence into the previous words' identities to fall, then this happens especially for words with a low quality level (recall, however, that a low lexical quality level does not necessarily lead to a low confidence level). In response, a regressive eye movement to this word of low quality is performed in order to increase the quality level which in turn increases the confidence level of this particular word.

In those rare cases of regressions where the increased quality level does not lead to a higher confidence level (e.g., in anomalous sentences), this increasing quality is used to re-compute the confidence level of the other words in the sentence and to trigger another regressive or progressive eye movement (or to finally abandon the attempt if no coherent sentence interpretation can be found).

(3) Sentence wrap-up effects

A clear deficit of eye movement models like SWIFT and E-Z Reader is that they attribute regressive eye movements only to processing difficulties. Whereas this of course covers a wide range of regressions reported in the literature, it ignores some important results at the same time.

Several studies provide clear evidence for an increased probability to regress from the end of a sentence (Frazier & Rayner, 1982; Meseguer et al., 2002; von der Malsburg & Vasishth, 2011, 2013). These so called 'sentence wrap-up effects' occur largely unaffected by sentence processing difficulties, or at least not showing up at the location in the sentence where difficulties are expected to become apparent (although other reading measures indicate difficulties at these locations, e.g., increased first pass reading times). Thus, these regressions cannot be directly attributed to failures of the lexical integration, for example. In addition, although the target positions of these regressions are rarely reported, most of these regressions seem to target the beginning of the sentence, thus resulting in rereading from the beginning (von der Malsburg & Vasishth, 2011, 2013).

As discussed above, the IGF is not restricted to processing difficulties, it rather posits that regressions are triggered whenever the predictions made by previous input are not matched. This could either be that the current input conflicts with the predictions (which would lead to a decrease of confidence) or that expected evidence is missing (which would lead to a slower increase of confidence). In the case of regressions from the final region we assume that the latter scenario takes place.

Thus, if the eyes move to the final (or pre-final) word, the confidence level of this word is computed by matching the predictions. But in addition, the punctuation is also received from the visual input (at least parafoveally), which signals a sentence boundary. Sentence boundaries indicate that no additional input for the current sentence interpretation can be received and subsequently no prediction (condition-action pair) can be postponed to later input. Thus, at the end of a sentence an evaluation of the whole sentence interpretation takes place (Just & Carpenter, 1980; Rayner et al., 2000; Hirotani et al., 2006). In the case that this evaluation reveals that more evidence is needed in order to develop a coherent sentence interpretation, a regression is performed to compensate for this information deficit. Of course, the degree of evidence (and of confidence, respectively) into a sentence structure that is assessed to be sufficient (the backward threshold) may depend on factors like task or time pressure.

Since an evaluation of the whole sentence takes place without dealing with a concrete integration problem, it is reasonable to assume that not a single target position based on the production rules can be defined. In contrast, the regression strategy applied selects a target position on the basis of language experience. This prediction fits well with the regression patterns reported by von der Malsburg & Vasishth (2011, 2013), which show a clear tendency for readers to regress to the beginning of the sentence and to read the whole sentence again.

(4) Fixation times and regressions

In the beginning we mentioned the counterintuitive finding of Altmann and colleagues (1992) that fixations before regressions tend to be shorter relative to fixations before progressions. Whereas these results may be interpreted in favor of the claim that increased fixation times and a higher number of regressive eye movements have to be functionally distinguished, the architecture of the IGF in addition directly predicts this pattern.

Recall that fixation durations are mainly monitored by the forward threshold: As soon as the confidence level of word n reaches the forward threshold, the eyes move to word n+1. If, however, the computation of the confidence level of word n-1 reveals integration difficulties (please recall that the computation of the confidence level of word n-1 still continues during a fixation of word n), this causes the confidence level of word n-1 to fall. As a consequence, the fixation of word n is cancelled and a regressive eye movement is performed instead. Because the fixation of word n is cancelled, fixation times before regressive eye movements tend to be shorter.

Predictions of the Information Gathering Framework

We have now seen, how the IGF may account for a variety of empirical findings reported in the literature. Another important factor supporting the strength of a model, however, is that it allows for further predictions. In the following, we will therefore discuss several more predictions that can be derived from the architecture of the model. But note that not all predictions discussed here will potentially verify or falsify the model. For example, the IGF assumes that new input is matched against predictions arising from previous input, which is one of the core principles of the model. If we were to find empirical evidence against this assumption, this would question the validity of the model. But whether these predictions are accomplished on the basis of production rules, by contrast, does primarily affect the detailed architecture of the model but not its core principles.

(1) Regression targets within and outside the perceptual span

The IGF makes a strong prediction with regard to the target selection of regressions: Only words within the perceptual span, which is assumed to comprise about 15 characters to the left of the current fixation, can be selected as a regression target by an explicit linguistic computation. Words outside of the perceptual span are assumed to only be selected by a backward strategy. This division should be reflected by the empirical data somehow.

First, it would be a quite unexpected finding if the regression landing sites show, for example, a Gaussian or a linear distribution over the sentence, thus ranging from very short to very long sizes with no further distinctions. We would rather expect that the majority of regressive saccades land within the perceptual span. In addition, we would expect that we are able to find a clear pattern for regressions that land outside the perceptual span because these regression targets are assumed to be selected by a strategy. And a regression strategy (even if more than one exists) should not lead to a random distribution of landing sites but to landing site patterns, which in turn help us to identify the applied strategies.

Second, in the case that there exists a well-defined target position from a theoretical linguistic point of view (as for example, in garden path sentences), we would expect that this defined target position is selected as a regression target only if it is within the perceptual span. If the ambiguous word is outside the perceptual span, for instance, no preference for a selection of this word is predicted, unless it is selected by the strategy.

(2) Shorter fixations durations before regressions due to integration difficulties but not before regressions due to missing evidence

As we have already discussed before, fixations tend to be shorter when they are followed by a regression compared to cases when they are followed by a progressive saccade. We have also seen how the IGF may account for this finding. But our model makes an additional prediction: Because regressions due to missing evidence are not triggered before the fixation of the current word is completed, we would expect no shorter fixation durations for these types of regressive eye movements (in contrast to regressions due to integration difficulties where a fixation is cancelled and thus the fixation durations are shortened).

(3) Independency of forward and backward threshold

Within the IGF it is assumed that the duration of first pass reading times is monitored by the forward threshold on one hand and the probability to regress by the backward threshold on the other. Although there is considerable evidence that these two thresholds highly interact (as for example indicated by the speed-accuracy tradeoff), we assume that these two parameters can be set independently.

Thus, we predict that there are cases where a more risky forward strategy does not necessarily lead to an increased probability of regressions. On the other hand, there should be cases where the probability of regressions is increased despite the fact that there are no longer first pass reading times.

(4) Regressions are sensitive to task modulations

Since regressions are assumed to be mediated by both the forward and backward threshold, we would expect that an adjustment of these thresholds should have an impact on the probability of triggering a regression. In particular, top-down influences like task or time pressure should affect the regression behavior during reading leading to more or less regressions, respectively.

Testing the Information Gathering Framework

In the last section we described the architecture of the IGF and also outlined some predictions that can be derived from the framework. In the following we will look for further empirical evidence by applying these predictions to an experiment conducted by Weiss and colleagues (Weiss, Kretzschmar, Schlesewsky, Bornkessel-Schlesewsky, & Staub, 2018).

Table 1: Example stimuli used by Weiss et al. (2018). Abbreviations: N = non anomalous, A = anomalous, H = highly associated, L = low associated, SRC = subject relative clause, ORC = object relative clause.

1. Semantic Reversal Anomalies (SRA)		
(a)	On a sunny afternoon | the girl | is picking | the flower | for the dining table.	NH
(b)	On a sunny afternoon the girl is drawing the flower on a little sketchpad.	NL
(c)	On a sunny afternoon the flower is picking the girl for the dining table.	AH
(d)	On a sunny afternoon the flower is drawing the girl on a little sketchpad.	AL
2. Relative Clause Sentences (RC)		
(a)	The chef | that distracted the waiter | sifted the flour onto the counter.	SRC
	(I) Did a chef do something?	easy
	(II) Did the waiter distract the chef?	difficult
(b)	The executives | that the lawyers sued | roused themselves from slumber.	ORC
	(I) Did a policeman do something?	easy
	(II) Was it the executives who roused themselves?	difficult
3. Garden Path Sentences (GP)		
	John borrowed | the rake or the shovel | turned out to be sufficient.	
	(I) Is there a shovel?	easy
	(II) Might the rake have been borrowed?	difficult

In this experiment, 92 English native speakers were asked to read 99 English sentences in total while their eye movements were monitored. These English sentences contained 36 Semantic Reversal Anomalies (SRAs), 39 Relative Clause Sentences (RC) and 24 Garden Path Sentences (GP; see Table 1 for an overview), where each of the RC and GP sentences was followed by a comprehension question. Crucially, the question difficulty was manipulated between subjects: While one group received only easy comprehension questions (e.g., probing for a word), the other only received questions that required a deeper understanding of the sentence. Let us now see how the IGF may account for the results.

(1) Task manipulation should only affect regression rates

From the perspective of the IGF, we expect that the task manipulation should adjust the backward threshold. Thus, in the easy condition the subjects should have applied a more superficial reading strategy compared to the difficult condition which set the backward threshold to a lower level. More precisely, the IGF makes the strong prediction that this task manipulation should only affect regression rates but not first pass fixation times.

Interestingly, that is exactly the pattern that was found in the data. For the SRAs, the anomaly effect became apparent in first pass reading irrespective of the task manipulation. However, although the question type did not affect first pass reading behavior, difficult questions induced significantly more regressions. We may interpret these results as evidence for adjusting the backward threshold independently of the forward threshold by using different reading strategies.

(2) Task manipulation should only affect regressions of type II (missing evidence)

A second prediction that can be directly derived from the model's architecture is that adjusting the backward threshold should only affect regressions of type II (due to missing evidence) but not regressions of type I (due to integration difficulties). Thus, we would expect to find an increasing number of regressive eye movements from the end of a sentence but not from the regions before.

Again, the reported results are in line with this prediction: In all three sentence types there was a significant increase of regressions out of the last 2–3 words of a sentence for the difficult condition. This was not the case for the regions before. Thus, the backward threshold seems to only affect regressions of type II (due to missing evidence) but not regressions of type I (due to integration difficulties).

(3) Shorter fixation times before regressions of type I (integration difficulties)

The IGF makes the strong prediction that fixations before regressions should be shorter compared to fixations preceding progressions, but only of regressions of type I (due to integration difficulties). This means that we should find shorter fixation times before regressions in all sentence regions except the last region, where we expect to find either no or a reduced effect of saccade type.

In order to test this prediction, we re-analyzed the data by identifying all inter-word saccades of the SRAs (n=41.800) and categorized them as progressive (n=31.671) or regressive eye movements (n=10.129), respectively. After that we attributed these saccades to the six regions of the sentence (for an example of the regioning-scheme, see Table 1).

A first analysis revealed that fixations before regressions were generally shorter (mean 217.06 ms) than fixations before progressive saccades (mean 222.84 ms). This difference of about 6 ms was highly significant ($t(14691) = 4.92$, $p<.001$). Looking at the means for the single regions, we also observed that this difference ranged from about 10 to 22 ms in regions 1–5 but dropped to about 2 ms in the last region (see Figure 4). We checked if this difference was significant by fitting a linear mixed effect model of the log fixation duration of the preceding fixation. For this we combined regions 1–5 to a new region (region_early) and compared this with region 6 (region_late), treating SACCADE TYPE and REGION as well as their interactions as fixed effects.

We also used random intercepts for subjects and items and took the maximal random effect structure. Following convention, we treat $t>|2|$ as significant.

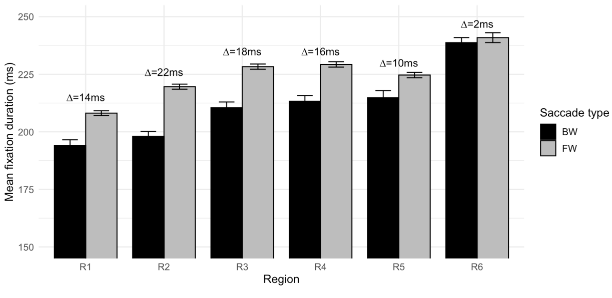

Figure 4: Mean fixation durations before saccades for all inter-word saccades of the SRA sentences, given for each region and saccade type separately. For details of the regioning-scheme please refer to Table 1. Abbreviations: R = sentence region, BW = fixation before a regressive saccade, FW = fixation before a progressive saccade, ms = milliseconds.

The results of the linear mixed effect models showed that SACCADE TYPE ($ß$ = .07, SE = .01, t = 6.28) and REGION ($ß$ = .10, SE = .01, t = 7.31) as well as their interaction ($ß$ = -.05, SE = .02, t = -2.48) had a significant impact on fixation durations. Thus, although fixations before regressions were generally shorter (indicated by the significant effect of SACCADE TYPE), this effect was significantly reduced in the last region of the sentence (indicated by the significant interaction of SACCADE TYPE X REGION).

This somewhat surprising finding fits well with the prediction made by the IGF: Because only regressions of type I (due to integration difficulties) are triggered in the way that the preceding fixation is cancelled, only fixations before these regressions should be shorter.

Another interesting, although unrelated finding is that fixation durations generally increase during the course of the sentence (indicated by the significant effect of REGION, see also Figure 4). In terms of the IGF this points to idea that the amount of information that has to be dealt with increases during the course of the sentence which leads to longer computation times until the forward threshold of confidence is reached. It might be worthwhile to examine the reasons for that in more detail by future research.

(4) Landing site distributions of regressive eye movements

Although the IGF is not very specific with regard to the landing site distributions yet, we nonetheless would expect to find that the perceptual span of about 15 characters to the left of the current fixation is reflected in the data somehow. Thus, we first computed the amplitude of all regressive eye movements in the SRA sentences (see Figure 5).

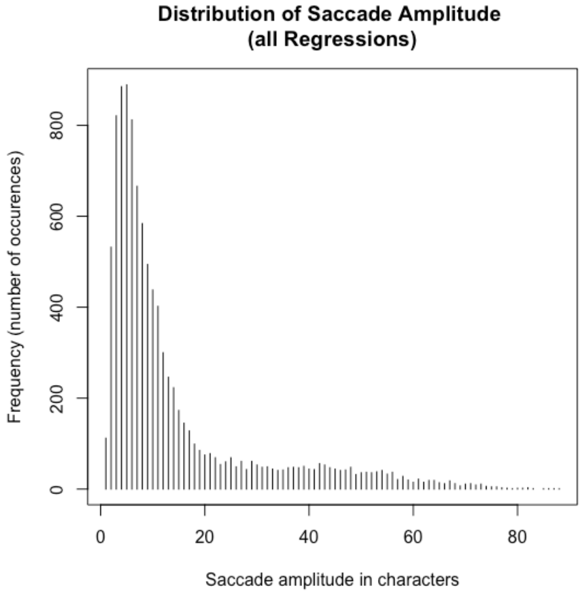

Figure 5: Distribution of saccade amplitude for all regressions in the SRA sentences. X-axis shows the saccade amplitude in characters and the y-axis the number of occurrences.

This analysis revealed that 74.81% of all regressions fell within the 15-character window left to the current fixation. However, because we took all regressions, the distance to the beginning of the sentence was reduced for some of them. Thus, we conducted a second analysis and restricted it to regressions that were initiated in the final region only (using the regioning scheme outlined above). As becomes apparent from Figure 6, we see a similar pattern, but the proportion of regressions within the 15-character window dropped to 51.61%. Anyway, at about 15 characters there seems to be again some kind of invisible boundary for which the probability to be crossed by a regressive eye movement is clearly reduced. This fits well with the assumption of the IGF that the linguistically driven selection of target positions is limited by the perceptual span which comprises about 15 characters to the left of the current fixation for regressive eye movements.

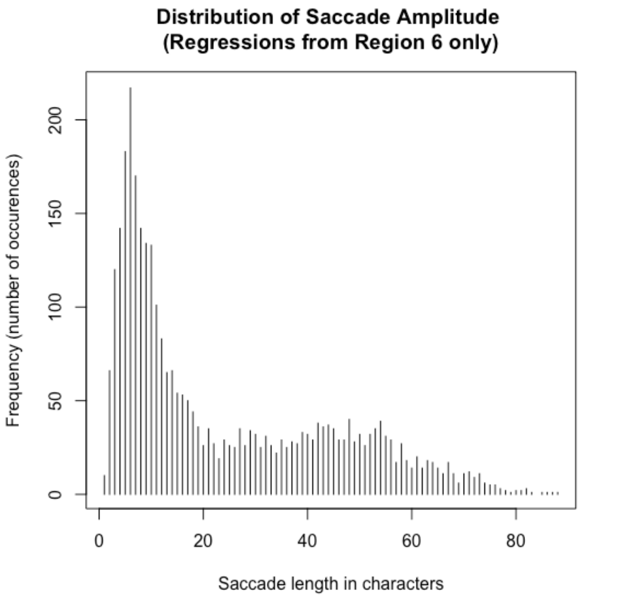

Figure 6: Distribution of saccade amplitude for regressions that were initiated in the final region of the SRA sentences only. X-axis shows the saccade amplitude in characters and the y-axis the number of occurrences.

Because the number of characters varied within sentences and regions, the saccade amplitude it not very meaningful with regard to the actual location in the sentence where the regressions landed. Thus, we further investigated the landing site distributions by aligning the target positions with the six sentence regions defined above. When taking all regressions into account we see a clear tendency to target the first region of the sentence (29.51%), thus probably resulting in subjects rereading the whole sentence again (see Figure 7). When only focusing on regressions from the final region, we see again an increased tendency to regress from the sentence beginning (14.45%) but the substantially more regressions (33.18%) landed in the pre-final region (which is a quite expected pattern given the results of the amplitude analysis above). These results are fully in line with the predictions of the IGF: The majority of regressions target a position within the perceptual span but if they cross this span, most likely a strategy is applied which is for subjects to reread the whole sentence again. This also fits well with the regression patterns reported by von der Malsburg and Vasishth (2011, 2013).

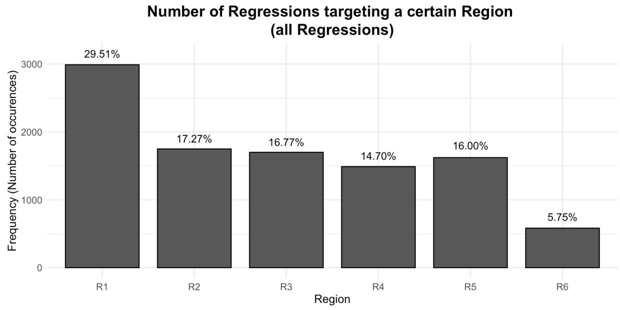

Figure 7: Number of all regressions of the SRA sentences targeting a certain sentence region (for details of the sentence regioning-scheme, please refer to Table 1). The percent values represent the proportion of all regressions.

However, because the experiment was not designed to conduct an analysis on the landing-site distributions, factors like region length were not controlled. Thus, these results just give a first impression but stress the need to investigate the target pattern of regressive eye movements in more detail by future research.

Conclusions

In this article we introduced a new eye movement framework that especially focuses on regressive eye movements during reading: The Information Gathering Framework (IGF). Based on the FC model proposed by Bicknell and Levy, the basic idea of the IGF is that a confidence level for each word is computed while being monitored by two independent thresholds: the forward and the backward threshold, respectively. These two thresholds shape the eye movement behavior by increasing fixation times or triggering a regression. Importantly, within the IGF it is assumed that two different types of regressive eye movements exist which differ with regard to their releases (integration difficulties vs. missing evidence) but also with regard to their time course. By re-analyzing an experiment of Weiss et al. (2018) we found, inter alia, clear evidence for shorter fixation durations before regressive saccades relative to progressive saccades, with the exception of the last region. These results confirm the predictions of the IGF. The IGF also proposes that a linguistically driven computation of the target positions should only be possible within the perceptual span which covers about 15 characters to the left of the current fixation. Our data suggests that the 15-character window indeed plays an important role within the target selection process.

However, both the architecture and the testing of the IGF are not fully sufficient yet but only provide a first tool for future research. So, it became clear that regressive eye movements are not just an 'error message' but seem to play an important role in developing a successful and fast reading strategy. Nonetheless, the details of their role for word identification, but also for sentence and text reading as well as their interaction with language comprehension are still unclear (but see e.g. Schotter et al., 2014, for a discussion of this problem). In addition, there are still many open questions with regard to the time-course and landing-site distributions of regressive eye movements. But we are convinced that the IGF allows us to derive precise questions for future research which will in turn give us good answers to understand the role of regressive eye movements during reading in more detail.

Ethics and Conflict of Interest

The author declares that the contents of the article are in agreement with the ethics described in http://biblio.unibe.ch/portale/elibrary/BOP/jemr/ethics.html and that there is no conflict of interest regarding the publication of this paper. Note that the model that is presented in this paper is part of the doctoral dissertation of AFW, submitted at Philipps-University of Marburg and online available at http://archiv.ub.uni-marburg.de/diss/z2017/0719

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