

Chapter 16

Eye Movement Measures to Study Global Text Processing

Jukka Hyönä, Robert F. Lorch Jr and Mike Rinck

In this chapter, we demonstrate the usefulness of the eye tracking method in studying global text processing. By “global text processing,” we refer to processes responsible for the integration of information from sentences that are not adjacent in the text. Potential eye movement measures indexing global text processing are discussed using as examples the processing of topic-introducing sentences and the processing of inconsistencies. In addition to the existing measures of regional gaze duration and lookback fixation time, we advocate new measures that may be applied to the study of global text processing. These include a new extended first-pass fixation time measure that allows lookbacks to previous text regions without necessarily terminating the first-pass reading, and first-pass rereading time that sums up all the reinspective fixations made during first-pass reading. We also demonstrate the potential usefulness of analyzing the origin and destination of eye movement sequences, such as lookback sequences.

Introduction

The goal of the present chapter is to consider the applicability of the eye tracking method to study global text processing. The starting point is that eye tracking has been successfully adopted to the study of basic reading processes and to that of syntactic parsing, but there are surprisingly few studies where eye tracking is employed to examine global text processing (but see Blanchard & Iran-Nejad, 1987; Hyönä, 1995; Hyönä, Lorch & Kaakinen, 2002; Kaakinen, Hyönä & Keenan, 2002; Vauras, Hyönä & Niemi, 1992). There may be several reasons for this state of affairs, but we focus on one likely reason; namely the apparent lack of consensus on the measures to be used to tap into global text processing. In what follows, we will consider the

applicability of conventional eye movement measures to the study of global text processing, and we will also suggest new, potentially useful measures.

Global Text Processing

We begin by defining what we mean by global text processing. Global text processes are those processes that identify and represent relationships between pieces of text information that span relatively long distances in a text. Our definition excludes mental processes related to building coherence between consecutive sentences and focuses on processes that link together information from sentences that are not adjacent in the text.

Global text processing probably becomes more concrete by the following examples. The first type of global text processing pertains to cases where successful comprehension requires a reinstatement in working memory of information mentioned in the preceding text. For example, in expository text, it is common that the writer probes the reader to reactivate relevant prior information (“As mentioned earlier . . .”, “Recall that . . .”). This may be achieved mentally, but it may also involve overt behavior, such as rereading the to-be-reinstated information. An example of a reinstatement process related to the comprehension of narratives pertains to activating in working memory the goal of the main character’s current actions. It has been shown that information about the goal is pertinent to the interpretation of the various actions carried out by the protagonist (van den Broek & Lorch, 1993). When the relevant goal information is not active in the reader’s working memory, it may be retrieved by rereading the text where this information is provided. Yet another example of this type of global text processing concerns the comprehension of inconsistencies in meaning between two text segments. Inconsistencies must be resolved if the reader wishes to build an internally coherent representation of the text. Resolving inconsistencies may require reprocessing of text segments that do not cohere with each other. Later in the chapter we will discuss in more detail how this type of global text processing could be studied with eye tracking.

A second category of global text processing that is discussed more thoroughly below has to do with processes pertaining to the comprehension of multiple-topic expository texts. A typical expository text is constructed around a global topic that is developed in a hierarchically related set of topics and subtopics. Thus, comprehension of such a text requires, in part, that readers represent the text’s topics and subtopics and their relationships. When a topic is identified, it, in turn, serves as a context for comprehending subsequent information that elaborates upon it.

Standard Eye Movement Measures

Eye tracking methods have been used most extensively to study lexical access and syntactic parsing. The measures that have been developed provide the researcher with information about the time course of processing. Thus, the measures can be divided into those that index immediate effects and those that index more delayed effects of

processing. In the study of lexical access (for more, see Inhoff & Radach, 1998), immediate effects have usually been studied using the *duration of the first fixation* on the critical word as the primary measure (see Table 16.4). The most widely used measure, *gaze duration* is also assumed to reflect relatively immediate effects in processing. Gaze duration is computed as the sum of all individual fixations landing on the critical word before exiting it. When there is only one fixation on the word, gaze duration equals first fixation duration (see Table 16.4). When refixations occur, gaze duration indexes less immediate effects than first fixation duration. For example, Hyönä and Pollatsek (1998; Pollatsek, Hyönä & Bertram, 2000) used these measures to study the identification of long compound words when they were embedded in sentences. They found that both the frequency of compound word constituents (first and second) as well as the whole-word frequency affected gaze duration, but only the frequency of the first constituent produced an immediate effect as reflected in first fixation duration.

For delayed effects, the following measures are widely used: the duration of first fixation after leaving the target word, the duration of regressions back to the target word, and the total fixation time computed as the sum of gaze duration and regression time (see Table 16.4). The common denominator for these measures is that they reflect events in the reader's eye behavior after the critical word is once exited. Total fixation time is a composite measure indexing both immediate and delayed effects. An example of a study showing a delayed effect in the absence of an immediate effect is that of Bertram, Hyönä and Laine (2000). These researchers sought evidence for the view that words are accessed via their constituent morphemes. They observed that for inflected words the frequency of the word's stem produced no immediate effects (i.e., no effects on gaze duration or first fixation duration), but a reliable lagged effect reflected in gaze duration for the $N + 1$ word.

As one moves from the study of lexical processing to syntactic processing, the potential units of analysis increase both in number and size. Whereas the word is the natural unit of analysis in lexical processing, there are four relevant levels of processing in the study of syntactic processing: (a) the word at which a parsing choice is expected to be made or a syntactic ambiguity to reveal itself, (b) the phrase, (c) the clause, and (d) even the whole sentence. Related to the increase in the number and size of potentially interesting units of analysis, the mental processing associated with syntactic processes is more complex and varied than the mental processing associated with lexical processing. Thus, syntactic effects on eye movements are correspondingly more complex than lexical effects on eye movements.

Studies of syntactic parsing have used a multitude of processing measures. Immediate and delayed effects in processing have been studied using first-pass and second-pass measures for the critical sentence regions. First-pass fixation time for a text region, which can be a word, a phrase, or a clause, is defined analogously to gaze duration as the summed fixation time on a text region before exiting it (either right or left). Murray (2000) proposes that it should be called gaze duration instead of first-pass fixation time, as it has been typically referred to in the syntactic parsing literature. Murray argues that separate names imply that these two measures would differ in some ways, although their underlying principle is exactly the same. Although we agree with this argument, we use a slightly different term, *regional gaze duration*, to avoid

confusion with the standard gaze duration related to single words (see Table 16.4). The second-pass fixation time that has been suggested to measure more delayed effects in parsing (e.g., a reanalysis of the syntactic structure) is analogous to the regression time measure used in the word identification studies (see Table 16.4). As the name indicates, the measure sums up fixations that return to a text region after it has been fixated at least once (i.e., during the first-pass reading).

In recent parsing studies, a measure often called regression path reading time has gained increased popularity (see e.g., Konieczny, 1996; Liversedge, Paterson & Pickering, 1998). This measure was invented to capture difficulty effects in parsing that were obscured in the standard measures (for more details, see Liversedge *et al.*, 1998). For example, when encountering a text region that entails syntactic ambiguity, readers may quickly go back to previous parts of the sentence to start over the parse in order to resolve the ambiguity (see also Vonk & Cozijn, this volume). This type of behavior would be reflected in shorter regional gaze durations for the region revealing the ambiguity — an effect opposite to what would be predicted. On the other hand, the predicted disruption in processing is shown in the reinspective fixations landing on earlier sentence regions. The regression path measure is designed to index exactly this kind of processing difficulty effect. To compute the regression path reading time, the researcher sums up all the reinspective fixations that occur once the target region is reached and before exiting the target region to the right (see Table 16.4). The distinctive feature of regression path reading time is that it sums up temporally contiguous fixations regardless of their spatial locations (as long as they are directed to previous sentence regions with respect to the target region). An alternative to this procedure is to cluster the fixations constituting the regression path on the basis of their spatial location, in which case they would be defined as second-pass fixations for the sentence regions they land on. Liversedge *et al.* (1998) demonstrate that this alternative to the regression path reading time may substantially weaken the chances to detect a disruption effect.

Within the regression path, it is possible to further separate out fixations that are directed from the target region to earlier sentence regions from fixations that land on the target region during its first-pass reading (i.e., prior to backtracking). These reinspective fixations constitute a measure called rereading time (Liversedge *et al.*, 1998) or first-pass regression time (Van Gompel, Pickering & Traxler, 2001). An example of a study in which all the measures mentioned above were utilized is that of Van Gompel *et al.* (2001). The study established no effect of attachment ambiguity in the first-pass fixation time, but reliable effects in the regression path reading time and the rereading time. These results were taken as evidence for the view that the studied type of syntactic ambiguity primarily increases the likelihood of computing a reanalysis of the syntactic structure.

Could the standard eye movement measures summarized above be applied to the study of global text processing? It is perhaps quite obvious that sentence- or clause-level measures of eye behavior will be more relevant than word-level measures. This is because the expected effects are rarely confined to individual words but to larger text regions. Thus, the measures of regional gaze duration and second pass fixation time as well as regression path reading time developed in the syntactic parsing research

may be readily applicable to the study of global text processing. On the other hand, it is possible that even larger units of analysis may need to be defined (e.g., an entire paragraph or a subsection). Moreover, some types of global processing may appear with notable delays, which may pose a need for new measures so that all aspects of global processing would become apparent from the eye tracking records. In what follows, we present a more detailed description of two types of global text processing, one related to the processing of a text's topic structure and another related to resolving textual inconsistencies. For each case, we discuss how eye tracking can be applied to tap the processes and what measures, existing or new, will be needed to conduct a thorough analysis of the eye behavior in question.

Case Study 1: Processing Topic-introducing Sentences

Sentences that introduce new discourse topics in an expository text place heavy processing demands on readers. Examine the excerpt from a descriptive expository text presented in Table 16.1. This excerpt consists of the first four (abbreviated) paragraphs from a text that compares and contrasts two fictional countries with respect to several attributes. The topic sentences of the third and fourth paragraph have been singled out for consideration ("Topic₁" and "Topic₂," respectively), along with the final sentence of the third paragraph ("End₁"). These examples illustrate two important functions of topic sentences with respect to the global structure of a text. First, a topic sentence is an explicit statement of a macroproposition; that is, it is a superordinate statement that integrates several of the statements in the paragraph or subsection in

Table 16.1: Excerpt from an expository text discussing characteristics of two fictional countries.

Although the countries of Culatta and Morinthia share a border, they differ in many different ways. In this article, we will discuss what makes each country interesting and unique.

The population of Morinthia is comprised primarily of the descendants of European immigrants. Most of the settlers came to the country in the 18th century. They consisted mainly of poor families who were willing to risk the unknowns of a new and unsettled country for the opportunity to own land and build their futures.

The people of Culatta have a fascinating history. (Topic₁) Physically and culturally, they are quite distinct from the people of the bordering countries. They are descendants of a race and culture that has existed in the country for at least 12,000 years. **Scientists hypothesize that the race originated in Asia. (End₁)**

The geography of Morinthia is striking in its contrasts. (Topic₂) The western border of the country consists of a rugged mountain range that plunges to the sea. East of the mountains is a vast tropical jungle that dominates the central part of the country. . . .

which it is placed. Second, when it is placed in a paragraph-initial position, a topic sentence serves to introduce a new discourse topic.

Consider the topic-introducing function of (many) topic sentences. An adequate understanding of an expository text requires that readers represent the major topics of the text and their relationships (Gernsbacher, 1990; Kieras, 1981; Lorch, Lorch & Matthews, 1985). As explicit statements of discourse topics, topic sentences are particularly relevant to the processing of the topic structure of a text (Kieras, 1980; Lorch *et al.*, 1985). At the time a topic sentence is first encountered during reading, it should entail relatively high processing demands. Indeed, topic sentences are processed more slowly than sentences that elaborate established discourse topics (Hyönä, 1994; Lorch *et al.*, 1985). In addition, a topic sentence is processed more quickly when the discourse topic it introduces can be related to the immediately preceding discourse topic than when it cannot (Lorch *et al.*, 1985; Lorch, Lorch & Mogan, 1987). These results are consistent with the hypothesis that readers update a representation of the text's topic structure each time they encounter a topic-introducing sentence and that the updating includes a computation of the relationship of the new topic to previously established topics. Additional support for this hypothesis is provided by the finding that rereading a text results in greater facilitation of processing of topic sentences than non-topic sentences (Hyönä, 1995). The selective speed up of rereading of topic sentences is presumably because readers do not need to construct a topic structure representation during the second reading of a text.

In addition to its topic-introducing function, a topic sentence integrates much of the information in the paragraph or subsection that it dominates. In fact, this is the defining characteristic of a topic sentence. As an important context for the interpretation and integration of subsequent information, readers might be expected to refer back to topic sentences with some regularity. For example, if readers encounter difficulty understanding a statement in a paragraph, they might attempt to relate the statement back to the topic sentence. Even in the absence of comprehension difficulties, readers might systematically refer back to topic sentences as part of a metacomprehension strategy to check understanding while reading. A particularly likely place to see evidence of such processing is the end of a paragraph (see End_1 in Table 16.1). The white space at the end of a paragraph and the corresponding preview of the indentation of the following line of text both predict a possible upcoming change of topic. Readers who systematically review their understanding as they read might be expected to show evidence of such a strategy at the ends of paragraphs. In fact, at least some readers use a strategy of looking back from "end" sentences to topic sentences and headings (Hyönä *et al.*, 2002).

Most of our knowledge of how readers process information about discourse topics while reading is based on experiments using single-sentence presentation of text. This is a serious limitation because it omits text layout information that is likely to be an important influence on the online processing of information relevant to the text's topic structure (Hyönä *et al.*, 2002). Further, the experimental procedure prevents readers from looking back to previous text and forces them to rely on memory for prior text. These correlated characteristics of the procedure are likely to distort our understanding of the nature of readers' strategies for processing topic-relevant

statements while reading. To consider how the use of eye tracking measures might augment our understanding of topic processing, we first elaborate the types of processes that might be involved in topic processing.

Topic Processing as Structure Building

Gernsbacher (1990) has proposed that shifts at all levels of structure in a discourse entail special processing efforts on the part of the reader. Applying her ideas specifically to the processing of topic structure, the following processing is hypothesized to occur when readers encounter a topic-introducing sentence. First, a topic sentence corresponds to a shift in the discourse structure from an old discourse topic to a new one. The reader responds to this shift by terminating processing of the current discourse topic and suppressing it (i.e., causing it to become less accessible). Further, a new structure is initiated to represent the new topic. We think of this shift to a new structure as involving moving from a subnetwork representing the previous section of the text, to finding the appropriate location in the text's hierarchical structure to start a new branch. Once this location is established (i.e., the relationship of the new topic to the existing topic structure representation is computed), it serves as the foundation for mapping new information. The reader continues to the next sentence and attaches the information in that sentence onto the new branch of the text representation. As long as the text continues to elaborate the new topic, information is mapped into the subnetwork corresponding to that topic.

Topic sentences play a critical role in coordinating the online processing of the text with the construction of the subnetwork representation associated with a topic. Encountering a topic-introducing sentence while reading triggers the reader to begin construction of a new subnetwork, as already described. Further, the topic sentence is an important point of access to the text representation. A reader who wishes to review information associated with the topic, or who needs to access specific information stored about the topic, must either rely on memory or must look back to the appropriate part of the text. If the reader consults memory, an effective strategy is to access the text representation by locating the relevant topic in the topic structure representation (i.e., locate the entry point to the appropriate subnetwork). If the reader wishes to search the text, an effective strategy is to find the topic-introducing sentence and search forward from that point.

Potential "Areas of Interest" in Tracking Topic Processing

The theoretical framework just described suggests at least four types of sentences that should be informative with respect to the nature of readers' attempts to process topic structure information during reading. In addition to topic sentences themselves, sentences that begin a new paragraph and sentences that conclude paragraphs and/or subsections may play a special role in a topic structure processing strategy. Of course, the initial sentence of a paragraph often is a topic sentence. Because this correlation

is presumably high and experienced readers are aware of it, paragraph-initial sentences may receive special attention from readers independently of whether they introduce a new topic. Finally, sentences that refer back to a previous topic at some point after discussion of the topic has concluded are also potentially informative about the nature of readers' representation and processing of a text's topic structure. We will restrict our discussion to topic sentences in considering how eye tracking measures may help us to understand topic processing during reading.

Suppose that readers perform the mental operations implied by the structure building framework (Gernsbacher, 1990) when they realize that the discourse topic has shifted. That is, they suppress the previous text topic, shift to the new topic, and initiate construction of a new subnetwork. Assuming that those operations require time and that they are initiated relatively close in time to when pertinent information is encountered during reading (Just & Carpenter, 1980), evidence of such processing should appear in the eye movement record sometime during reading of a topic-introducing sentence. But what unit of analysis is most appropriate to the detection of such effects? This is ultimately an empirical question that may not have a single, simple answer. In fact, the earliest possible effect of a topic shift might actually be before any part of the topic sentence has been fixated. Consider the sentence labeled "Topic₂" in Table 16.1. Readers could conceivably shift from the old topic during the course of reading End₁ on the assumption that each paragraph discusses a new topic (although such a strategy seems risky). This might appear as an increase in gaze duration on the final word and/or final verb phrase of End₁.

Even if they show some anticipation of a change of topics, readers cannot shift to a new topic until it is identified. If a single word fully communicates the new topic, then the earliest possible point at which this information becomes available is the first content word of the topic sentence. If the topic is communicated by a phrase as in the text illustrated in Table 16.1, then the initial noun phrase of the topic sentence is the earliest point at which the new topic may be identified. Thus, it is theoretically possible that topic processing might be initiated at the first new noun or the initial noun phrase containing a new noun. However, it is possible that readers do not commit themselves to updating their topic structure representations until the clause or sentence is completed. In that case, effects reflecting topic processing may not appear until the end of the clause or sentence. If so, defining the unit of analysis as the clause or sentence may be informative, although analyzing the final word or phrase of the topic sentence may catch "wrap up" effects. The situation may be even more complicated than this. Consider the possibility that readers are conservative about committing to a change of topics until the new topic is confirmed by the following sentence. This hypothesis stretches the immediacy principle uncomfortably (Murray, 2000), but researchers have observed such "spillover effects" in studies of readers' processing of global coherence relations (Myers, O'Brien, Albrecht & Mason, 1994). In short, analyses at the various grain levels that have been investigated in other studies are also likely to be useful in the application of eye tracking methods to the study of topic processing while reading. Further, we would like to hold open the possibility that still larger units of analysis may be relevant to the study of topic processing. Given that topics dominate paragraphs and even larger sections of text, these larger units of text

organization may be useful units of analysis in the study of online topic processing. For example, if a statement refers to information established earlier in a text, a reader might search backwards through the text for the relevant information. Such a search process might be organized according to text layout information such as paragraph indentation or headings within the text (Klusewitz & Lorch, 2000).

Potential Measures of Topic Processing

Again, it is largely an empirical question as to what processing measures may be most informative in the study of topic processing. Nevertheless, we might anticipate that topic processing lags somewhat behind the theoretically earliest points at which such processing might be initiated. If that turns out to be the case, then measures of initial processing (e.g., regional gaze duration) will not reveal topic processing effects. Further, it is likely to be the case that the most useful units of analysis will be units larger than single words. In that event, much of the conventional arsenal of eye movement measures (e.g., gaze duration on individual words, probability of fixation, probability of regressing from or to a given word) will not be applicable (Inhoff & Radach, 1998; Rayner, 1998; Rayner, Raney & Pollatsek, 1995). Rather, the most useful measures will be of two sorts. First, conventional measures of the processing of phrases and sentences such as regional gaze duration, total reading time, and the probability of looking back from or to a phrase or sentence (see Table 16.4; and Rayner, 1998; Rayner *et al.*, 1995). Second, measures that attempt to analyze how readers search for information relevant to understanding a statement that they are processing (Liversedge *et al.*, 1998; Murray, 2000).

If the structure building framework provides a reasonable approximation to the (topic) processing involved in understanding a topic sentence, there are many alternative ways in which such processing might be manifested in eye movement records. One possibility is that readers can rely on memory to access the information needed to comprehend a topic sentence (at least some readers some of the time); therefore, they can complete all necessary processing of the topic sentence without looking back to preceding sentences or forward to subsequent sentences in the text. In this situation, the more conventional eye tracking measures should be sensitive to the nature of the readers' topic processing. Consider one hypothetical scenario for the example of Topic₁ in Table 16.1.

For Topic₁, the information that the discourse topic has changed is first available when the word "Culatta" is fixated because it is at this point that it is clear that the country under discussion has changed. Readers might demonstrate sensitivity to the change of topic in several ways. If readers respond immediately to the topic switch, then their initial fixation duration on "Culatta" should be slow (relative to an appropriate control). If their response is a little delayed, gaze duration and total time on "Culatta" might be relatively long. The pattern of regressions within a topic sentence may also provide useful information about when readers commit to a change of discourse topic. Specifically, regressions may be initiated from "Culatta" back to the start of the sentence if readers respond relatively immediately to a potential topic

change; alternatively, readers may often launch regressions from the end of a sentence that introduces a topic change (Hyönä, 1995).

If readers must identify where to attach the new topic in their text representation, this computation probably involves retrieving the preceding text topic (i.e., population of Morinthia) and determining that the two topics should attach to the same superordinate (i.e., the general topic is the people of the two countries). When this computation occurs during the course of reading the topic sentence is an open question. It might occur before a forward fixation from the word “Culatta”; it might occur in the course of sentence wrap-up; it might be delayed still further. This uncertainty might be resolved by comparing the processing profile of Topic₁ with the processing profile of a topic sentence that introduces a topic whose location in the text structure is less easily computed (e.g., Topic₂ in Table 1), (cf., Lorch *et al.*, 1985, 1987).

It is entirely possible that readers will not rely exclusively on their memories to do all necessary processing of topic sentences. Rather, they may search the text for relevant information (Liversedge *et al.*, 1998; Murray, 2000). In that event, some conventional measures may not be very meaningful. For example, if readers often interrupt processing of a topic sentence before reaching its end, it is not clear how to interpret a measure like regional gaze duration or even total fixation time (Liversedge *et al.*, 1998). To elaborate, suppose that in the course of reading Topic₂, a reader begins looking back to the previous text after reading the initial noun phrase but before any fixations occur on the verb phrase. There are at least two measurement problems here. First, by its conventional definition, the look away from the sentence terminates regional gaze duration despite the fact that the reader has not completed processing of the sentence. If regional gaze duration is intended as a measure of the initial processing of a sentence, then an appropriate measure must attempt to aggregate the initial fixations on all parts of a sentence. That is, when the reader returns to a sentence that was incompletely processed before a look away, first-pass reading on the remainder of the sentence should be added to first-pass reading on the initial part of the sentence (see Hyönä & Juntunen, submitted, for an example of such an algorithm). We will call this measure *extended first-pass fixation time* (see Table 16.4).

The second measurement problem concerns the lookbacks themselves. We define “lookbacks” as all fixations that occur on text that is prior to the most recently-fixated sentence. Thus, lookbacks include both regressive fixations and forward fixations. Assuming that the lookbacks are triggered by an attempt to process the information in the topic sentence, analysis of the lookbacks is critical to understanding the reader’s processing of the topic sentence. To begin with, it is informative if a lookback (or series of lookbacks) is initiated after processing the noun phrase of Topic₂. In the structure building framework, this action might be interpreted as a demonstration that the reader has recognized the change of topic and is attempting to compute the location of the new topic (i.e., geography of Morinthia) in the text representation. In this example, readers may well search back to the paragraph about the population of Morinthia because that was the last mention of a common superordinate. If the readers’ memory for the location of that paragraph and its topic sentence is less than perfect, the search back may involve several fixations on intervening material or a jump back to the beginning of the text followed by a forward search. In a text with headings, there might be

a systematic search utilizing the headings to identify potentially relevant information about the relationship of the new topic to previous text topics. In short, it is plausible to imagine multiple fixations on prior statements that vary in their relevance to the processing that the reader is attempting to complete. In this circumstance, the landing position of the initial lookback is unlikely to correspond to the goal of the search. Rather, a more thorough analysis of the pattern of lookbacks would be in order.

If processing of a topic sentence is interrupted by a series of lookbacks to prior text, several measures may be jointly informative. One potentially useful measure is the time between the initiation of a lookback sequence and the first forward fixation past the location from which the sequence was initiated, or “rereading time” (Liversedge *et al.*, 1998; see Table 16.4). Rereading time provides information about the amount (or difficulty) of processing necessary at some point in time, but it is not informative about the nature of that processing. The sequence of fixations along with information about the relative duration of fixations may begin to reveal what a reader is trying to compute. The sequence of fixations alone may not be very informative because some fixation locations may not provide the reader with useful data; rather, they may just be the consequence of less than perfect memory for the location of potentially useful text information. When a lookback does land the eyes on a relevant text location, however, the reader will presumably spend more time inspecting that phrase or sentence. Thus, a record of the total lookback time on each sentence (or smaller unit of analysis) during a lookback sequence provides information about what information the reader found most useful. Putting together the information about where the lookback sequence originated, how the prior text was searched, and what information received the most attention during the sequence should provide important information about what computation the reader was attempting to perform and how the computation was accomplished.

Finally, as an index of the relative difficulty of understanding a particular sentence, it may be useful to sum the duration of all rereading times within the sentence before a forward fixation is made to the next sentence. The assumption here is that if readers are having difficulty understanding a sentence, they will reprocess it before continuing to the next sentence. Thus, the extended first-pass rereading time on a sentence provides a measure of the extent of difficulty in comprehending the sentence (Hyönä *et al.*, 2002). Of course, the assumption underlying the use of this measure may be wrong. Perhaps there are times when a reader attempts to resolve a comprehension problem by reading ahead. In such cases, a comprehension difficulty may manifest as looks back to the problematic sentence shortly after reading ahead.

Case Study 2: Processing Inconsistencies

Inconsistencies and the Updating of Situation Models

What does it mean to “understand” a text? Recent theories of text comprehension agree on at least a partial answer: deep comprehension of a text involves the creation and updating of situation models (e.g., Gernsbacher, 1990; Kintsch, 1988, 1998; van Dijk

& Kintsch, 1983; Zwaan, Langston & Graesser, 1995; Zwaan & Radvansky, 1998). A situation model is a representation of the situation described by the text, rather than a representation of the text itself. Situation models are multidimensional; they contain information about the causal, temporal, and spatial relations of the situation. In case of narrative texts, the represented dimensions also include the protagonists' goals, traits, beliefs, and emotions. Moreover, a situation model needs to be consistent, that is, it has to represent a state of affairs that is possible in the world described by the text (this does not exclude states that are only possible in fictional worlds such as fairy tales).

Zwaan and Radvansky (1998) proposed a detailed account of how readers construct situation models during text comprehension. In their general processing framework, they distinguish between three types of situation models: the current, the integrated, and the complete model. They also distinguish four types of processes operating on these models: the construction, updating, and retrieval of situation models, and the foregrounding of specific situation model elements. According to their framework, readers construct a current model of the situation described by a sentence or clause. As they continue reading, each sentence yields a new current model. The information from all sentences read so far is being integrated into a single model, which is therefore called the integrated model. The process of incorporating a new sentence into the integrated model is called updating of the model. During reading and updating, readers may focus more on some types of information than on others, a process called foregrounding. When all sentences have been read, the integrated model is stored in long-term memory as the complete model. Later, the complete model or elements of it may be retrieved from memory in an attempt to remember what has been read (see Zwaan & Radvansky, 1998, for details of these processes).

Inconsistencies affect this chain of processes by interfering with updating of the situation model: If a sentence contradicts earlier ones, it becomes difficult or even impossible to update the current model and to create a consistent integrated model. Inconsistencies have been used in many studies to explore the different types of information represented in situation models. The general argument in these studies is the following: If readers represent a certain type of information in the situation model, they should exhibit comprehension difficulties upon encountering a sentence that is inconsistent with regard to this information. For instance, the current model might represent the protagonist of a narrative as *located inside* a building. If the protagonist's spatial location is indeed represented in the situation model, readers should find it difficult to integrate a sentence stating that the protagonist *went inside*. In fact, inconsistencies such as this one were used to demonstrate the representation of spatial information in situation models (e.g., O'Brien & Albrecht, 1992; de Vega, 1995). Other studies employing this paradigm revealed the representation of emotional information (e.g., Gernsbacher, Goldsmith & Robertson, 1992) character information (Albrecht & O'Brien, 1993; de Vega, Diaz & Leon, 1997), and temporal information (Rinck, Hähnel & Becker, 2001) in situation models created from narratives. In addition, inconsistencies contained in expository texts yielded similar comprehension difficulties (Lorch, Shannon, Lemberger, Ritchey & Johnston, 2000).

Most of the studies employing this *inconsistency paradigm* have not used eye tracking to study the processing of inconsistencies. Instead, reading times of single

sentences were recorded. This may be illustrated by the following sample text taken from Rinck *et al.* (2001).

1. Today, Mark and Claudia would finally meet again.
- 2a. Mark's train arrived at Dresden Central Station 20 minutes *after* Claudia's train.
- 2b. Mark's train arrived at Dresden Central Station 20 minutes *before* Claudia's train.
3. Mark was very excited when his train stopped at the station on time.
4. He tried to think of what he should say when he met her.
5. Many people were crowding on the platform.
6. Claudia was already waiting for him when he got off the train with his huge bag.
7. They both were so happy.

Participants read this text (without the italics) one sentence at a time in a self-paced manner, and reading time of each sentence was recorded. Each participant read either Sentence 2a or Sentence 2b. Sentence 6 is consistent with Sentence 2a, but inconsistent with Sentence 2b: Claudia cannot be waiting for Mark, if he has arrived before her. Therefore, participants who have read 2b should find it more difficult to integrate Sentence 6 into their current situation model than participants who have read 2a. The critical dependent variable was reading time of the sixth sentence, and indeed, a strong *inconsistency effect* occurred: Reading time of Sentence 6 was reliably longer in the inconsistent version of the text (see Rinck *et al.*, 2001, for details).

There are a number of reasons why it may be advantageous to record eye movements within the inconsistency paradigm. First and foremost, eye tracking measures may yield additional information about the processing of inconsistencies; information not available from the "sentence-by-sentence reading" version of the paradigm. Just as topic processing, the processing of inconsistencies may be distorted by the presentation of single sentences because it prevents readers from looking back to previous sentences and forces them to rely on memory instead. Second, many studies have used the inconsistency paradigm, yielding large and reliable inconsistency effects on reading times for many different dimensions of situation models. Thus, we are dealing with an effect which is general as well as reliable. Third, the experimental manipulations employed in the inconsistency paradigm may be neatly controlled, excluding confounds of experimental conditions and materials. Thus, for each text it is possible to compare an inconsistent version to a consistent one, while the two versions are almost identical in wording. Finally, the most critical locations relevant for eye tracking measures are fairly obvious, namely the two sentences that contain the potentially conflicting pieces of information (Sentence 2 and Sentence 6 in the example above).

Potential "Areas of Interest" in Tracking Inconsistency Processing

Most of the texts employed to study inconsistencies were structured very similarly: A critical sentence appearing early in the text (e.g., the second sentence in the example above) explicitly states a critical piece of information. A number of sentences (usually at least three of them) follow, which are consistent with both versions of the critical

sentence and with following the target sentence. The target sentence is presented next (e.g., as the sixth sentence in the example above). This sentence is either consistent with all previous information or it explicitly contradicts the information contained in the earlier critical sentence. Thus, the critical sentence and the target sentence are most crucial for processing of the inconsistency. For all participants, comprehension of the text should proceed smoothly up to the target sentence. As soon as the target sentence is presented, however, processing should differ. While readers of the consistent target sentence should not exhibit any comprehension problems, readers of the inconsistent sentence should find it difficult or even impossible to integrate the sentence into the current situation model. If they notice the inconsistency (not all of them do, see Rinck *et al.*, 2001, 2002), they should engage in repair processes in order to resolve the apparent inconsistency. Although the nature of these repair processes has not been investigated in detail, a number of possibilities seem plausible: First, readers might go on reading, hoping to find a resolution in the following sentences. Second, they might doubt the validity of their current situation model, wondering whether they misunderstood earlier parts of the text (e.g., the critical sentence). Third, they might disbelieve the target sentence rather than the current model, wondering whether the target sentence contains a mistake. Finally, they might try to solve the comprehension problem by elaborating possible resolutions for the apparent contradiction. Using sentence reading times, it is impossible to tell which of these repair processes is occurring because all of them are compatible with the increase in reading time observed for inconsistent target sentences compared to consistent ones.

Existing and Potential Measures of Inconsistency Processing

From the possible repair processes just outlined, a number of promising eye tracking measures may be derived. Using these, the goal is to tell how processing of inconsistent statements differs from processing of consistent ones, and what kind of repair processes are likely to occur during the processing of inconsistencies. In order to do so, Rinck *et al.* (2002) as well as Lorch and Lemberger (2001) recorded eye movements during the reading of narratives and expository texts, respectively. In both studies, complete texts were presented instead of single sentences, and the participants were free to look back and forth during reading. Also, sentences rather than words or phrases were used as the unit of analysis, similar to the suggestions made above for the study of topic processing. Some of the measures suggested in this chapter — although not all of them — may be illustrated by the experiments reported by Rinck *et al.* (2002). In this study, individual eye fixations within a single sentence were ignored, but individual fixation durations were summed up to yield regional gaze duration for each sentence. Eye movements from a sentence to another sentence presented earlier were analyzed as *lookbacks*, whereas *regressions*, i.e., backward eye movements within sentences, were not separately analyzed. Within these restrictions, Rinck *et al.* (2002) computed the following measures: *Regional gaze duration* of a sentence was defined in the standard way as consisting of all fixations within the sentence during the first reading of it, before moving on or moving back to a different sentence. The

summed duration of lookback fixations comprised the *second-pass fixation time*. Finally, *total text fixation time* was computed by summing up all fixation times registered for the text (see Table 16.4).

Using these measures, it was possible to identify eye movement patterns associated with the processing of inconsistencies. For instance, with regard to temporal inconsistencies, Rinck *et al.* (2002) found that an inconsistent sentence does not seem to cause readers to fixate this sentence for a longer time due to the increase in processing difficulty. Thus, regional gaze durations and second-pass fixation times of the critical target sentences did not mirror the sentence reading times observed in earlier experiments. Rather, the inconsistency caused readers to look for information that might be used to check and resolve the inconsistency. As we hypothesized above for topic processing, it was also found for inconsistency processing that lookbacks did not always land directly on the critical second sentence. However, most of the lookbacks were indeed aimed at the second sentence where readers would find the conflicting piece of information. Thus, more lookbacks to the second sentence and longer second-pass fixation times of this sentence were observed in the inconsistent condition compared to the consistent one. Longer second-pass fixation times were also observed for the final sentence of the text, indicating that readers also checked this sentence for an explanation of the inconsistency.

Rinck *et al.* (2002) concluded that the inconsistency effect observed with single-sentence presentations may lack ecological validity: no increase in regional gaze duration of the target sentence was observed, indicating that the increase in sentence reading time is an artifact of the single-sentence presentation. If readers are able to see the complete text, they do not stay with the sentence containing the inconsistent information. Instead, they look back to related information earlier in the text or move on to the next sentence searching for an explanation. The single-sentence presentation does not allow for this type of visual search; it forces readers to perform a memory search instead. It seems that the commonly used sentence-by-sentence reading paradigm reliably indicates that inconsistencies do cause *some kind* of additional processing. Measures of eye movement patterns, however, may supply a much better picture of *what* these additional processes may be.

In addition to the fairly standard measures employed by Rinck *et al.* (2002), other measures may prove to be useful as well. In general, these measures are similar to those suggested for topic processing. There we suggested a measure of *extended first-pass fixation time* for which the first-pass reading is *not* terminated by a lookback sequence to a previous sentence provided that (a) a lookback sequence is initiated well before completing reading the sentence and (b) that the reader returns to the sentence to read the remaining part of it (see Table 16.4). Using this new measure, an effect of inconsistency may be established also for the target sentence, as the effect may be obscured in the regional gaze duration measure due to its premature termination by a lookback sequence initiated in the middle of the sentence. An apparent weakness in the new measure is that it obscures the information about first-pass reading consisting of two temporarily separate fixation sequences intervened by a lookback sequence. This weakness could be remedied by tagging these trials as such, which would then make possible their exclusion or inclusion in the analyses (see also Vonk & Cozijn, this

volume). Moreover, *total lookback time* may be recorded for the text preceding the target sentence. This measure would yield the total time invested to solve the textual inconsistency. Thus, it is similar to rereading time and regression path measures used in the study of syntactic parsing (Liversedge *et al.*, 1988; Van Gompel *et al.*, 2001).

With texts consisting of a fairly limited number of sentences, it is also feasible to record all between-sentences movements and store their frequencies in an *eye movement matrix*, which shows how often readers moved their eyes from any possible starting sentence to any possible destination sentence (see Table 16.4), similar to the transition matrix suggested by Ponsoda, Scott and Findlay (1995). Again, within-sentence eye movements would be ignored in the eye movement matrix. For instance, looking back from the second sentence to the first sentence and making several fixations on the first sentence would be counted as one movement sequence. A sample matrix of this kind is shown in Table 16.2. This matrix contains hypothetical data that might be collected during reading of consistent texts made up of seven sentences: There are only a few lookbacks, they are distributed fairly evenly across all sentences, and most eye movements lead from one sentence to the following one. Moreover, the matrix contains a pattern of lookbacks that Rinck *et al.* (2002) did indeed observe: many lookbacks lead from the final sentence to the first sentence because participants tended to reread every text, in order to prepare for a comprehension question following each text.

In comparison, Table 16.3 contains hypothetical eye movement sequences that one might expect to observe during reading of inconsistent texts. In this matrix, there are more lookbacks, and particularly more lookbacks from the sixth and seventh sentence towards the critical second sentence. These eye movement matrices are particularly informative when used to compare two experimental conditions contained in short texts. With more conditions and more sentences, the matrices may become too many and too large, the number of movement sequences in each cell too low, and the observed patterns too complicated to allow statistically significant conclusions. Moreover, instead of simply counting the number of eye movement sequences (or their percentages) in each cell, it might be informative to include the *fixation durations* following

Table 16.2: Hypothetical eye movement matrix for consistent texts.

Starting sentence	Destination sentence						
	1	2	3	4	5	6	7
1	–	89	4	2	5	3	2
2	5	–	93	1	7	0	1
3	9	4	–	91	1	2	4
4	3	9	2	–	88	4	3
5	2	6	4	3	–	95	2
6	8	5	6	8	6	–	83
7	35	8	7	6	9	7	–

Table 16.3: Hypothetical eye movement matrix for inconsistent texts.

Starting sentence	Destination sentence						
	1	2	3	4	5	6	7
1	–	79	14	12	10	8	2
2	15	–	83	9	12	29	6
3	19	14	–	81	11	7	9
4	13	19	22	–	78	11	8
5	12	16	14	13	–	85	5
6	18	45	16	18	16	–	93
7	29	38	17	16	19	17	–

the movements as well. As argued above for topic processing, it may be important to distinguish which sentences are processed from how long they are being processed. In any case, the matrices may be most useful in generating hypotheses regarding typical eye movement patterns associated with different experimental conditions, if precise hypotheses have not been derived a priori from a theoretical basis. In doing so, later analyses may be restricted to the most important cells of the matrix, for instance, those involving the second and the sixth sentence of consistent versus inconsistent texts.

For the processing of inconsistencies, it is also possible to derive hypotheses regarding the most frequent *eye movement scan paths* (see Table 16.4). For consistent texts, these paths should follow the linear order of sentences “1–2–3–4–5–6–7”, possibly repeated once in preparation for a comprehension question. For inconsistent texts, paths including lookbacks to the second sentence should be more frequent, for instance “1–2–3–4–5–6–2” or “1–2–3–4–5–6–7–2”. This pattern of results was indeed observed by Rinck *et al.* (2002), although the analyses were not powerful enough to yield statistically significant differences. With more powerful designs, it may be possible to show that some prototypical paths occur more often in one experimental condition than in another. These analyses would add further information to the results obtainable with eye movement matrices.

Finally, all eye movement measures of inconsistency processing discussed so far are based on sentences as the unit of analysis. This is convenient and useful, but sometimes it may be more appropriate to study smaller units of inconsistent texts. For instance, the target sentence “*Claudia was already waiting for him when he got off the train with his huge bag*” shown above could be rewritten to “*When he got off the train, Claudia was already waiting for him*”. For this sentence, only the second clause is consistent or inconsistent with earlier information. Therefore, regional gaze durations and second-pass fixation times might be restricted to the second clause instead of the complete sentence. An even narrower focus may be applied to texts that have been used to investigate emotional inconsistencies. With single-sentence presentation, emotional inconsistencies have yielded extremely large inconsistency effects. The

materials used in these studies do not contain any explicit statement of the protagonist's emotional reactions. Instead, readers have to infer the reactions from the contents of the story, which they reliably do (e.g., Gernsbacher *et al.*, 1992). For instance, a story may describe how the protagonist commits a crime, for which a close friend is blamed and punished. The target sentence then states that the protagonist “felt extremely guilty” versus “felt extremely proud”. Thus, the consistent target sentence and the inconsistent one differ by only one word, rendering fixations of this target word and eye movements originating from it particularly interesting. On the other hand, there is no explicit statement that is being contradicted by the target word. Therefore, it will be particularly challenging to identify the eye movement patterns associated with processing of emotional inconsistencies.

Summary

In the present chapter, our aims have been twofold. First, we have tried to demonstrate the potential applicability of eye tracking to study global text processing. Despite its apparent usefulness, the method has been applied only infrequently for this purpose. One reason for the paucity of such studies is probably the fact that in the existing literature, no standards have been developed for specific measures to be used. Thus, our second goal in the present chapter has been to discuss the potential usefulness of existing eye movement measures and to suggest new measures capable of reflecting different aspects of global text processing. The most important measures discussed in this chapter are shown in Table 16.4. To sum up our discussion, we list in the following the measures that we believe hold the most promise for the study of global text processing. The default unit of analysis is here assumed to be the sentence, although the measures may also be applied to other text units.

Existing Measures

1. **Regional gaze duration:** Summed duration of fixations made on a text region before exiting it.
2. **Lookback fixation time** (or second-pass fixation time): Summed duration of fixations that return to a text region after its first-pass reading.

New Measures

3. **Extended first-pass fixation time:** It differs from the conventional regional gaze duration in allowing fixations to previous text regions in the middle of first-pass reading without terminating the first-pass reading, as long as the reader returns to the target region to complete reading it. This would mean that the reader makes a series of fixations that land further into the sentence than any of the fixations prior to backtracking (see Hyönä & Juntunen, submitted).

Table 16.4: Eye movement measures described in this chapter.

Measure	Standard or common unit	Timing of effects	Definition
First fixation duration	Word	Immediate	Duration of first fixation on the target word
Gaze duration	Word	Immediate	Summed duration of all fixations on the target word before exiting it
First fixation duration after leaving	Word	Delayed	Duration of first fixation after leaving the target word
Regression	Word	Delayed	Fixation of previously processed target word, usually associated with “backward” eye movement
Regression time	Word	Delayed	Duration of all regressions back to the target word
Total fixation time	Word	Delayed	Sum of gaze duration and regression time
Regional gaze duration (First-pass fixation time)	Region (word, phrase, clause, sentence)	Immediate	Summed duration of all fixations on the target region before exiting it
Lookback fixation time (Second-pass fixation time)	Region	Delayed	Duration of all regressions back to the target region
Regression path reading time	Region	Delayed	Summed duration of all reinspective fixations before exiting target region to the right
First-pass rereading time	Sentence	Delayed	Summed duration of all reinspective fixations on the target sentence during its first-pass reading
Lookback	Sentence	Delayed	Any fixation on text prior to the most recently fixated target sentence, including backward and forward fixations as long as they do not return to the target sentence
Lookback time	Sentence	Delayed	Duration of lookbacks

Table 16.4: continued.

Measure	Standard or common unit	Timing of effects	Definition
Extended first-pass fixation time	Sentence	Immediate and delayed	Sum of first-pass fixation time and additional fixation times on target sentence, if (a) lookbacks occur before completing the target sentence and (b) eyes return to remaining part of sentence before fixating later sentences
Total text fixation time	Sentence	Immediate and delayed	Sum of all fixations on complete text
Eye movement matrix	Sentence	Immediate and delayed	Contingency table containing the frequencies or durations of all between-sentence movements, from any starting sentence to any destination sentence
Scan path sequence	Sentence	Immediate and delayed	Frequency of a particular sequence, in which the sentences are fixated.

Note: The terms “time” and “duration” have been used synonymously in the literature.

4. **First-pass rereading time:** Summed duration of all reinspective fixations landing on the target region during its first-pass reading. By definition, reinspective fixations are fixations that land on a subregion (i.e., word) that has already been fixated. A reinspective cycle is initiated by a regression, but subsequent fixations may be either regressive or progressive (see Hyönä *et al.*, 2002).
5. **Eye movement matrices:** This measure is applied to the analysis of eye movement sequences between text regions. For example, going back from region N to region $N-3$ and making a series on second-pass fixations on region $N-3$ is considered a lookback sequence, whose origin is region N and destination region $N-3$. Both the frequency of between-region movements (see Tables 16.2 and 16.3) and the summed duration of fixations constituting the movements may be analyzed.

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