Brief report

Microsaccadic behavior when developing a complex dynamical activity

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Abstract
Microsaccades are sensitive to changes of perceptual inputs as well as modulations of cognitive states. There are just a few works analyzing microsaccades while subjects are processing complex information and fewer when subjects make predictions about upcoming events. To evaluate whether contextual predictability might change microsaccadic behavior, microsaccades were evaluated for twenty-one subjects when reading 40 regular sentences and 40 proverbs. *Maxjump* was defined as the word with the largest difference between the cloze predictability of two consecutive words. Analysis of microsaccades while reading proverbs and regular sentences revealed that microsaccadic rate on words before *maxjump*, during *maxjump* and words after *maxjump* varied depending on the kind of sentence and on the word predictability. Words of low and high predictability required either less or more microsaccades to previous words, during and on *maxjump*, depending upon the semantic context and a readers' predictions of upcoming words. The present study demonstrates that the rate of microsaccades showed significant differences for reading either proverbs or regular sentences. Hence, evaluation of microsaccades while reading sentences with different contextual predictability may provide information concerning specific effects of cue attention during a complex task.

Keywords
Microsaccade; reading; proverbs; attentional cue; predictions

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1. Introduction

Reading, eye movements, and visual attention are closely related. Readers acquire visual information during brief periods of fixation that are separated by saccades. The major function of saccadic eye movement is to move words into the fovea for close inspection during the subsequent fixation [1]. Although it is common to use the term "fixation", an acute examination of motor activity between saccades reveals that the eyes are never immobile. During these periods, small eye movements occur that consist of the continual alternation between miniature saccades (i.e. microsaccade) and periods of relatively slow eye drifts [2]. It has been proposed that microsaccades provide a mechanism for relocating gaze in high acuity tasks [3]. Investigators have reported that microsaccade properties are sensitive to changes of perceptual inputs as well as modulation of cognitive states [4, 5]. It has been shown that microsaccades follow spatial attention, suggesting that microsaccades are an expression of ongoing physiological processes, whose main functions might be the maintenance of gaze fixation [1].

Reading is useful for understanding how eye movements and cognitive functions act together. There have been large syntactic and semantic reading studies undertaken with the goal of understanding how word properties and contextual predictability affects eye movement [6, 7]. Nevertheless, the effect of how subjects perform real-time word processing and how this impacts microsaccade modulation is still unknown. The analysis of microsaccades during the reading of sentences with different cloze predictability (i.e., regular sentences and proverbs) could provide new answers.

Recent works suggest that overt shifts of attention and eye movements are linked to visuospatial memory [8, 9]. Also, known targets enhance the speed and accuracy with which stimuli are detected and discriminated [10, 11]. Thus, visuospatial attention and oculomotor planning may reinforce and help to produce stronger visual representations. Investigators have proposed that expectations act as an attentional filter to facilitate the extraction of information. The prevailing view is that the prefrontal cortex (PFC) mediates this pre-stimulus activity modulation. Extensive evidence suggests that the PFC generates cortical processing in visual areas via cognitive (i.e. top-down) signals prior to stimulus presentation [12–14]. Expectation, or anticipation, that precedes the presentation of a stimulus and can be predicted is a type of top-down modulation that has been shown to involve the PFC [10]. Investigators suggest that, due to prediction, the PFC facilitates goal-directed saccades [15]. On the other hand, the superior colliculus (SC), the top-level brainstem structure involved in the control of saccadic eye movements [16, 17], has been identified as a key neural structure for microsaccadic generation [18, 19]. Recently, it was proposed that the PFC provides an excitatory input to the SC to facilitate task goals [15].

To date, there have been few studies that have explicitly investigated microsaccadic behavior during the performance of complex tasks and even fewer cases that have studied the prediction of upcoming events [20]. Analysis of sentences with different predictability provides an excellent tool for understanding microsaccadic behavior in complex top-down processes. The hypothesis here is that contextual predictability would probably change the microsaccade rate due to top-down attentional cues. To test this hypothesis, it was investigated whether the properties of a sentence affected microsaccade rate. To this end, proverbs and regular sentences were employed as reading material. When reading proverbs, there is typically a word at which not only the next word but the entire sentence becomes predictable. To capture this sharp transition in predictability that occurs when a subject matches an entire sentence being read to one held in memory, the word with the maximum change in cloze predictability was determined (see Methods section for more detailed description) relative to the previous word in a given sentence. In the context of reading, this word was referred to as the *maxjump* word [7]. Consequently, the words in a sentence were divided into three groups, depending on their position in relation to the *maxjump* word. In the first group of words were words before the *maxjump* word, in the second group was the *maxjump* word and in the last group were the words following the *maxjump* word. Eyetracker was used to evaluate the effect of predictability of different groups of words on microsaccade rate.

2. Methods

Data were acquired from 21 readers (all native Spanish speakers), mean age 28 (SD = 4.2 years) and mean education 18.2 years.

Putative subjects diagnosed with ophthalmologic diseases such as glaucoma, visually significant cataracts, or macular degeneration, or having a visual acuity less than 20/20 were excluded from the study.

2.1. *Apparatus and eye movement data*

Single sentences were presented on the center line of a 20-inch LCD Monitor (1024 × 768 pixels resolution; font: regular; New Courier; 12 point, 0.2° in height). Subjects sat at a distance of 60 cm from the monitor. Head movements were minimized using a chin rest. An EyeLink 1000 Desktop Mount (SR Research) eyetracker, with a sampling rate of 1000 Hz, was used to record the eye movements.

Subject gaze was calibrated with a standard 13-point grid for both eyes. They were instructed to read single sentences in silence. A random question related to a given sentence occurred in about 20% of the trials. Subjects used a computer mouse to choose one of three alternative options to provide the correct answer.

The sentence corpus was composed of 40 regular sentences (e.g. “Ayer charle con Laura acerca de su hija” English translation, “Yesterday I talked to Laura about her daughter”) and 40 proverbs (e.g. “Mejor pajaro en mano que cien volando” English translation, “A bird in the hand is worth two in the bush”). For full details of sentence and word properties, see Fernandez *et al.* [7].

The word with the largest difference between the cloze predictability of two consecutive words was determined according to the following equation:

$$\text{jump word} = \max[\text{Logit}(\text{pred}_{N+1}) - \text{Logit}(\text{pred}_N)].$$

The jump-word separates the sentence in three regions: before, during, and after *maxjump* word. With this *maxjump* variable the contextual word predictability effect due to memory retrieval was tested [7, 21].

The methodology employed to extract the microsaccade from each fixation, was based on Engbert and Kliegl [22].

3. Results

Word information is processed in the brain during fixations and during this process microsaccades are generated. It was hypothesized that context predictability would affect microsaccades. To investigate this hypothesis, changes in microsaccade rate were evaluated, when comparing proverbs and regular sentences. As shown in Fig. 1 the mean microsaccade rate for words previous to *maxjump*, during *maxjump*, and after *maxjump*, varied depending upon both the kind of sentence and on word predictabilities. When analyzing words previous to *maxjump*, words with either low predictability or words with high predictability exhibited well differentiated rates of microsaccade, which was also found to be the case for the analysis of proverbs and regular sentences. The microsaccade rate for words prior to *maxjump* in proverbs were 10.38 sec vs. 10.65 sec and in regular sentences were 10.26 sec vs. 9.90 sec, for low predicability words and high predictability words, respectively. It seems that proverbs required a higher rate of microsaccade (See Fig. 1). The difference between sentence types when considering microsaccade rate was significant ($p = 0.01$). For the *maxjump* words, the microsaccade rates for proverbs were 10.52 sec vs. 9.63 sec and in regular sentences, 10.26 sec vs. 9.63 sec, for low predictability words and high predictability words, respectively. In this case the rate of microsaccade was similar for both kinds of sentence and the effect of the sentence was not significant ($p = 0.95$). Finally, on words after *maxjump*, the microsaccade rate for proverbs were 10.30 sec vs. 10.26 sec and in regular sentences were 9.98 sec vs. 10.38 sec, for low predictability words and high predictability words, respectively. The difference between sentence types when considering microsaccade rate was significant ($p = 0.02$). Note that in this case regular sentences showed a major rate of microsaccade on high predictable words similar to those reported in proverbs when processing words on the previous *maxjump* (see Fig. 1).

4. Discussion

Several functions have been proposed for microsaccades: Counteracting perceptual fading, improving gaze in high acuity tasks, and following spatial attention [1, 23]. Reading material provides an important tool for analyzing microsaccadic behavior. The present results reveal that the rate of microsaccades showed significant differences when reading proverbs and regular sentences.

Analysis of microsaccades showed different mean rates for words previous, during, and after *maxjump*, and between proverbs and regular sentences. The microsaccade rate were higher when processing proverbs, in particular on words prior to *maxjump* (Fig. 1). This suggests the presence of a top-down microsaccade manipulation when processing proverbs, because a retrieval process was required for updating such words. When reading proverbs the predictability of words previous and after *maxjump* increased and decreased microsaccade rates, respectively. This particular effect suggests that microsaccade activity is present performing predictions about upcoming words, whereas in regular sentences these effects of word predictability seem to be the opposite, at least until after *maxjump*, where readers are able to form predictions of upcoming words [7] (see slopes Fig. 1). Increasing predictability in proverbs increased differences in word processing between both groups of sentences.

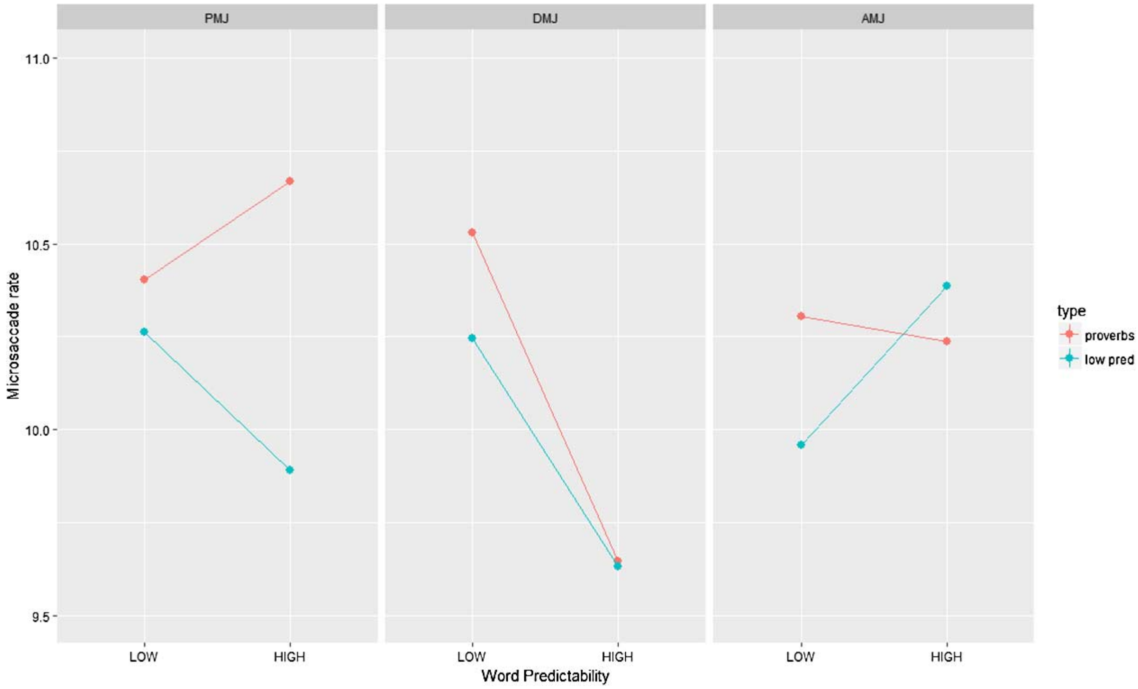

Fig. 1. The fixations analyzed are divided in words with low and high predictability. For each group of words the microsaccade rate prior to *maxjump*, during *maxjump* and after *maxjump* were analyzed. Mean microsaccade rate corresponding to proverbs (red) and regular sentences (turqoise) are illustrated.

Results imply that semantic context has an impact on microsaccadic rate, with microsaccades being actively involved during top-down processes for reading and anticipating words.

Recent reports suggest that the PFC contributes an excitatory signal that facilitates the generation of goal-directed saccades. As stated in the Introduction section, there is evidence that the PFC provides an excitatory input to the SC for facilitating behavioral goals [16]. The SC was identified as a key neural structure for microsaccade generation [18]. The prevailing view is that the PFC mediates this prestimulus activity modulation generating cortical processing in visual areas via top-down signals prior to stimulus presentation [24]. A type of top-down [13] modulation that has been shown to involve the PFC is expectation, or anticipation, which precedes the presentation of a stimulus that can be predicted [25]. Prediction is a fundamental aspect of visual perception. The present results show a clear relationship between microsaccade rate and prediction of upcoming words. Further, differentiated processing of microsaccade rate was needed for anticipating known words embedded in proverbs. Recently, the microsaccade of expert and novice ping pong players were analyzed where they had to predict pingpong ball trajectory [20]. Expert player feedback was associated with smaller values of microsaccade parameters. Such results are similar to those reported here, suggesting that better prediction modifies microsaccade rate.

It was recently suggested [26] that the inferior parietal lobe mediates the automatic allocation of attention to retrieved memory contents, while others [8] proposed that overt shifts of attention through eye movements are associated with higher accuracy of performance in relational visuospatial memory task [27–29]. It was argued that activation of these parietal lobe regions may reinforce and help to produce stronger relational spatial representations and, consequently, produce more accurate memory recognitions, while fewer bottom-up resources are used. This study showed that microsaccade rate can be influenced by cognitive cues in a specific task. Proverbs might provide an example of the specific effect of cue attention on ongoing word processing and microsaccade execution.

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Conflict of Interest

All authors declare no conflicts of interest.

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