

Low vision: understanding how low-level visual and oculomotor processes are specifically affected

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Dr Eric Castet is a researcher at the CNRS (National Center for Scientific Research) in Marseilles (Aix-Marseille University, France). He is a psychophysicist who started working on low-level visual processes involved in motion perception. Since 1999, he has been investigating how saccadic eye movements interact with visual perception and attention. These issues have mostly been tackled with a psychophysical approach either in fundamental or clinical research projects that were often led in parallel. Since 2005, he has been coordinating a research network with the department of ophthalmology in Marseilles (La Timone university Hospital) to study low vision with a focus on the psychophysics of reading and eye movements. He has received fundings from the CNRS, from the French national research agency (ANR) and from several low vision agencies (Fondation de France, Fondation de l'avenir). He also initiated and coordinated a 5-year project funded by the company Essilor International to develop and investigate gaze-controlled techniques to augment perceptual processes in low vision patients.

Symposium abstract

One of the goals of a psychophysical approach when investigating low vision is to understand the link between low-level visual factors and visual impairment for some important functions such as reading or face recognition. Low-level visual processes are intimately related to oculomotor processes, and comprehension of their relationship is thus an important challenge. The symposium will give an overview of this research field with an emphasis on studies of Age Related Macular Degeneration (AMD), a visual impairment whose main characteristic is Central visual Field Loss (CFL). Michael Bach (Germany) will start the symposium with a presentation introducing how new psychophysical tools allow us to accurately assess different levels of low vision across a very large range. Then, Peter Lewis (Sweden) will present work showing how a stimulus motion (a too often overlooked factor) can affect contrast sensitivity in the presence of CFL. He will be followed by Susana Chung (USA) who will start convincing us of the importance of studying the role of eye movements. She will show that fixational eye movements, despite their abnormal characteristics, help the processing of fine spatial tasks for people with AMD. Then, Aurélie

Calabrèse (France) will present her work on the link between reading speed and saccadic eye movements for people with AMD. Finally, Robin Walker (UK) will show how reading scrolling text is a technique that can improve reading performance in different ways when central visual field is lost. Overall, the goal of the symposium is to show that psychophysical investigations in this field, beyond improving our theoretical knowledge, have also the potential to help us design new functional tests, visual aids or rehabilitation techniques.

1. Functional impact of fixational eye movements in people with macular disease

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People with macular disease invariably exhibit highly unsteady fixational eye movements (FEMs), characterized by large amplitudes of slow drifts and microsaccades. What is the functional impact of these abnormal FEMs? A recent theory posits that slow-drifts of normal FEMs reformat the visual input of natural images, so that the amplitude of the spatial frequencies (SFs) of the input image is equalized across a range of SFs (“spectral whitening”), thus improving the processing of high-SF information. We tested whether the abnormal FEMs in people with macular disease also result in spectral whitening; and whether or not these FEMs are essential for fine spatial tasks. We first measured FEMs for observers with bilateral macular disease and age-matched controls with normal vision using a scanning laser ophthalmoscope (SLO). Segments of FEMs of various durations, without or with intervening microsaccades, were used to create movies that simulated how natural scene images moved on the retina due to FEMs. The spatio-temporal amplitude spectrum of each movie was computed using a 3D Fast Fourier Transform. Across all conditions, we observed spectral whitening (the amplitude spectrum of the movies simulating the effect of FEMs is virtually constant for SFs up to ~ 10 c/deg) even in observers with macular disease. Next, we compared observers’ performance accuracies for identifying the orientation of a sinusoidal grating in the presence of various amounts of natural FEMs, by stabilizing the retinal image of the grating at a range of stabilization gains using our SLO. Although observers’ accuracies were never the highest with natural (unstabilized) FEMs, they were only slightly worse than the best performance which was usually obtained with slightly less retinal image motion. Overall, we showed that despite the abnormal characteristics, a functional role of FEMs of people with macular disease is to help the processing of fine spatial tasks.

Grant support: NIH Research Grant R01-EY012810

2. Reading deficit with AMD: an oculo-motor pattern investigation

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Purpose: To study the oculomotor pattern of patients with central field loss (CFL) when reading continuous text. We explored the two following questions. 1- Through what underlying mechanism does the saccade amplitude (measured in Letters per Forward Saccade - L/FS) impact reading speed; 2- How does the horizontal distribution of fixations vary across sentences and how does it affect reading speed.

Methods: We measured eye movements of 34 AMD and 4 Stargardt patients (better eye decimal acuity: 0.08 to 0.3 logMAR) while they monocularly read single-line French sentences continuously displayed on a screen. All had a dense scotoma covering the fovea as assessed with MP1 microperimetry. To answer our first question, we developed an explicit model articulating the causal relationships that link: L/FS, fixation duration, number of fixations and reading speed. To explore our second question, we defined a new oculomotor factor: the non-uniformity of eye fixations (NUF factor), based on statistical analysis of fixation distribution.

Results: 1- Despite a large negative effect of fixation duration on reading speed, our model showed that the effect of L/FS on reading speed is fully caused (ie. mediated) by the total number of fixations and not by fixation duration. 2- Non-uniformity of fixations is a strong determinant of reading speed. This effect is not confounded with the effect of L/FS. The per-sentence proportion of trials with clustering is predicted by the frequency of occurrence of the lowest-frequency word in each sentence.

Conclusions: Our first set of results is consistent with the shrinking perceptual span hypothesis: reading speed decreases with the average number of letters traversed on each forward saccade, an effect fully mediated by the total number of fixations. Second, the NUF factor is a new oculomotor predictor of reading speed. This effect is independent of the effect of L/FS. The frequency effect suggests that reading performance, as well as motivation to read, might be enhanced if new visual aids or automatic text simplification were used to reduce the occurrence of fixation clustering.

Grant support: This work was supported by a *French Ministry of Research and Technology* grant.

3. Reading scrolling text: normal vision and with a loss of central vision

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Eye movements have been used to great effect in studies of reading over the past forty years. By contrast, few studies have investigated the dynamic horizontally-scrolling (Times Square) format despite it being reasonably commonly encountered in every-day life (for example: news tickers and LED announcement boards). The scrolling text format also has potential as a low-vision reading aid (the MD_evReader app) for people with macular degeneration. However, scrolling text presents particular challenges for the oculomotor and attentional systems, as the text must be tracked to the left (for a 'pursuit-fixation' on each word), whilst rightward saccades are required to progress along the sentence. We compared the oculomotor and linguistic characteristics of reading with horizontally-scrolling and static sentences in participants with normal vision. The typical lexical word-length and word frequency effects were preserved with shorter (pursuit) fixations observed with short and high-frequency words. Sentence-level integration was, however, reduced with the expected predictable word facilitation effects being impaired with the scrolling format. In studies of reading with a simulated loss of central vision (artificial scotoma paradigm), adherence to holding an eccentric viewing position was improved with the scrolling text format compared to reading static sentences. Participants with macular degeneration showed improved reading accuracy and a good reading speed with scrolling text and questionnaire ratings of their reading experience of the MD_evReader indicated a preference for reading with this app compared with their usual method.

4. Quantitative approaches to evaluating restored vision

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5. Enhancing peripheral vision in subjects with central field loss.

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