Long Term Persistence of Fixational Eye Movements

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1 Introduction
When we view a stationary scene, our eyes perform extremely small autonomic movements. These fixational eye movements are produced involuntarily and are characterized by three different movements: high-frequency small amplitude tremor, slow drift, and fast microsaccades. Generally, they serve to counteract retinal adaptation by generating small random displacements of the retinal image in stationary viewing. Studies of fixational eye movements have been going on since the 1950s, but the role of the drift and microsaccadic movements in the visual process is not yet fully understood [1,2,3]. Here we investigate the dynamic behavior of fixational eye movements using fluctuation analysis and detrended fluctuation analysis which have been used in a number of experiments dealing with biological time series.

2 Materials
Five participants of the University of Potsdam, Germany, took part in the experiment. Participants were required to fixate a small stimulus with a spatial extent of $0.12$ degree or $7.2$ arc min ($3 	imes 3$ pixels on a computer display screen on a white background). Each participant performed 100 trials with a duration of 3 seconds. Eye movements were recorded using an Eyelink system with a sampling rate of 500 Hz and an instrument spatial resolution of 0.001 degree (and accuracy is shown in Figure 1).

3 The Methods of Analysis
and study how the fluctuations $F(s)$ of the profiles increase with the length $s$ of a given time window. We employ a hierarchy of methods that differ in the way the fluctuations are measured and possible trends are eliminated [4]. We first divide each series of $N$ elements into int($N/s$) non-overlapping segments of size $s$. In the standard fluctuation analysis (FA) (where trends are not going to be eliminated), we determine the difference of the profile at both ends of each window. The square of this difference represents the square of the fluctuation in each window. In the $n$th order of detrended fluctuation analysis (DFA$n$) we determine in each window the best $n$th order polynomial fit of the profile. The profile from these best $n$th-order polynomials represents the square of the fluctuation in each window. In these ways we can get the fluctuations $F(s)$ by averaging over many time windows of size $s$. The long term persistence of the series is characterized by a power law $F(s) \propto s^\alpha$, \( \alpha \) is called a scaling exponent.

4 Conclusions
- There exist crossovers for the fluctuations of horizontal and vertical components (cf. Fig 2).
- From DFA, we find that the horizontal components are much more correlated than the vertical components on short time scale. After removing microsaccades, however, the scaling exponents decrease on short time scale, especially for the horizontal components (cf. Fig 2). Figure 3 summarizes the results for the scaling exponents obtained by DFA2.
- On long time scale, horizontal and vertical components exhibit anti-correlated behavior. After removing microsaccades the scaling exponents increase. Figure 4 summarizes the results for the exponents obtained by DFA2.
- Figure 5 summarizes the results for the scaling exponents obtained by FA for the vertical and horizontal components of left eye movements with and without microsaccades.

5 Discussions
- Horizontal and vertical eye movements are controlled by different brain stem nuclei. Microsaccades are more dominant in horizontal movements.
- Microsaccades enhance the persistence of two components on short time scale and are responsible for the anti-persistent behavior on the long time scale.

6 References