PSYCHOLOGICAL SCIENCE

Commentary

Microsaccade Orientation Supports Attentional Enhancement Opposite a Peripheral Cue

Commentary on Tse, Sheinberg, and Logothetis (2003)

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Tse, Sheinberg, and Logothetis (2003) exploited a change-blindness paradigm to map the redistribution of spatial attention in response to a peripherally flashed cue. The probability of change detection at a given location was used as a measure of attention allocation. Using this measure, a "hot spot" of attention (i.e., close to perfect change detection) was found along the cue-fixation axis. This hot spot extended in the hemifield opposite the cued location. Here we show that an analysis of fixational eye movements in a spatial-cuing paradigm supports this important finding.

During fixation of a stationary target, micromovements of the eyes occur involuntarily. These fixational eye movements are classified as drift, tremor, and microsaccades. Microsaccades are the fastest of these three components, with amplitudes typically smaller than 1° of visual angle. Using a classical spatial-cuing paradigm (Posner, 1980) with central arrow cues indicating the most probable location of a later target, we recently demonstrated that microsaccades are modulated by visual attention (Engbert & Kliegl, 2003b). About 300 ms after cue presentation, the angular distribution of microsaccades was oriented toward the expected target location.

In the study reported here, we used pilot data from a larger experimental study to examine the impact of peripheral cues on the rate and orientation of microsaccades. Using peripheral flashes—similar to the uninformative stimuli employed by Tse et al. (2003)—we found an orientation shift of microsaccades in the direction opposite the cued location. Taken together with our results on the coupling of visuospatial attention and microsaccades (Engbert & Kliegl, 2003b), these results are in agreement with the attentional enhancement opposite the cued location observed by Tse et al. (2003).

METHOD

Figure 1a illustrates the experimental procedure. Twenty-two participants performed 120 trials each. They fixated a central spot (size: 0.78°) during the entire trial and responded only with key presses. A cue (i.e., a 100-ms flash) was presented either to the left or to the right of the central spot, its position indicating the probable position (validity = 80%) of a subsequent target stimulus. Manual response latencies to targets showed benefits from valid cues (i.e., target at cue location) and costs from invalid cues (i.e., target opposite the cue location). Fixation accuracy was checked with an EyeLink-II system (SR-Research, Osgoode, Ontario, Canada) with a sampling rate of 500 Hz and an instrument spatial resolution better than 0.005°. Microsaccades were detected on the basis of a transformation of eye movements to two-dimensional velocity space (Engbert & Kliegl, 2003b). During data preprocessing, trials with missing data (blinks) or saccades with amplitudes larger than 1° were discarded. Final data analysis was based on 1,678 trials from all participants.

RESULTS

To detect changes in the angular distribution of microsaccades induced by the cues, we computed microsaccade rates (i.e., number of microsaccades per second) separately for orientations to the right and to the left. All microsaccades with a maximum angular deviation between −45° and +45° from the target direction were considered, because binocular microsaccades are predominantly horizontally oriented (Engbert & Kliegl, 2003a). Figure 1b displays the change in microsaccade rates after right and left cues (top and bottom panels, respectively). Rates were computed for each participant using a moving time window of 200 ms and then averaged over all participants; the shaded areas around the curves indicate between-subjects standard errors. There was no significant difference between

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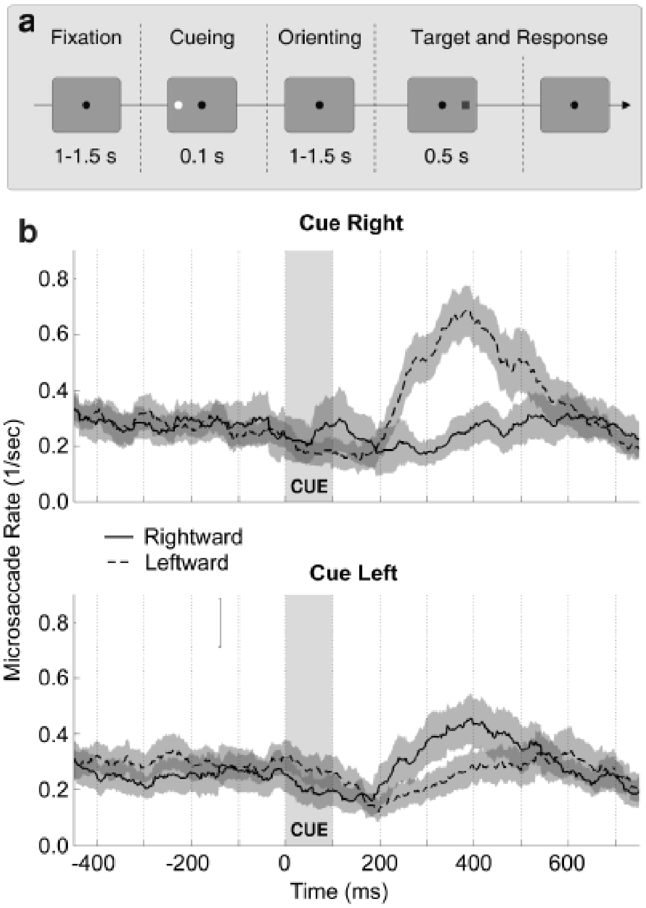

Fig. 1. Microsaccade rate in a spatial-cuing paradigm. The trial sequence is shown in (a). After 1 to 1.5 s, a cue (white circle, 12.7° eccentricity) was presented for 100 ms to the left or to the right of the central spot, indicating the most likely (validity = 80%) position of a target stimulus that appeared 1 to 1.5 s later for 500 ms (12.7° eccentricity). Participants were required to discriminate two possible target alternatives (a red vs. a green box) by pressing one of two buttons. Note that an invalid cue is illustrated in this example. The graphs in (b) show temporal changes of microsaccade rate plotted separately for right (top) and left (bottom) cues. The shaded area around each curve represents ±1 between-subjects standard error. The white areas between the rate curves in the postcue intervals from 250 ms to 400 ms indicate significant differences.

left-oriented and right-oriented microsaccade rates in the precue intervals, but there was a significant excess of microsaccades with orientations opposite the cue direction in a time window of about 250 to 400 ms after cue presentation, as reflected in a separation of the rate curves that was greater than two standard errors.

Given the coupling of visuospatial attention and microsaccade orientation (Engbert & Kliegl, 2003b), we conclude that visual attention was enhanced in a direction opposite cue location. Moreover, considering the delay of saccadic eye movements following shifts of attention, the time window was in good agreement with the fact that Tse et al. (2003) found the most pronounced attentional enhancement opposite the cued location at flash-target intervals of 176 ms and 247 ms.

DISCUSSION

These findings support the results of Tse et al. (2003) with a different experimental paradigm and dependent variable. In their own paradigm, Tse, Sheinberg, and Logothetis (2002) found that the peripheral-flash condition produced no modulations in fixational eye movements compared with a nonflash condition. Their paradigm included five display changes within a trial duration of less than 1.5 s, with stimulus-onset asynchronies between cue and target ranging from 12 ms to 447 ms. High-acuity instructions (Bridgeman & Palca, 1980; Winterson & Collewijn, 1976), as well as display changes (Engbert & Kliegl, 2003b; Reingold & Stampe, 2000), decrease the rate of microsaccades. Consequently, a rapid sequence of five display changes will induce a strong inhibition of microsaccades. This suppression of microsaccades might preclude the observation of modulations in fixational eye movement statistics, thereby accounting for the results of Tse et al. (2002), although modulations of neural activity related to oculomotor neurons might still be present.

How could microsaccadic oculomotor activity underlying covert shifts of visuospatial attention explain attentional enhancement opposite a cued location? To maintain fixation during and after cue onset, participants must inhibit (automatic) saccadic reactions toward exogenous cues. The population coding of saccade orientations in the superior colliculus (Lee, Rohrer, & Sparks, 1988) suggests that this inhibition results in a bias of activation of oculomotor neurons for movements to the opposite hemifield (see also Munoz & Istvan, 1998). Moore and Fallah (2001) showed that microstimulation of oculomotor neurons summoned attention to the visual space represented by the cortical stimulation site even when the stimulation was too weak to elicit any large-scale oculomotor activity. Obviously, then, oculomotor activity (such as shown in our study) can result in a hot spot of attention opposite a cued location, as observed by Tse et al. (2003).

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