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Individuals exhibit idiosyncratic eye-movement behavior profiles across tasks

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ABSTRACT

The purpose of this study was to examine individual differences in eye-movement behavior. Six metrics (Fixation Rate, Duration, and Size; Saccade Amplitude; Micro-Saccade Rate and Amplitude) were used to measure individuals' eye-movement behavior profiles (EmBP). We replicate previous research (Andrews & Coppola, 1999; Castelhano & Henderson, 2008) by finding consistent individual differences in fixation duration and saccade amplitude across tasks, and present new findings of stable idiosyncrasies in measures of fixational eye-movement (Fixation Size, Micro-Saccade Rate and Amplitude). Moreover, we observed consistent inter-metric correlations across tasks (e.g., individuals that exhibited relatively high Fixation Rates also presented relative low Micro-Saccade Rates and relatively high Micro-Saccade Amplitudes). Factor Analysis linked the six EmBP metrics together with a single factor, which we speculate might be related to the operational effectiveness of the attentional system, given that individual factor scores were correlated with scores on a self-report measure of attentional function. Normal subjects with relatively high scores on this attention-deficit measure exhibited relatively frequent fixations of short duration and large spatial extent, and relatively infrequent micro-saccades of large amplitude. This EmBP is similar to a general pattern of eye-movement behavior observed with ADHD individuals – difficulty controlling eye movements, maintaining fixation, and inhibiting intrusive saccades. Results of this study indicate that normal individuals exhibit idiosyncratic EmBPs that are quite stable across tasks and are related to attentional ability.

1. Introduction

All individuals with normal vision demonstrate similarities in eye-movement behavior that are present from early childhood through adulthood (Richards, 2001). Eyes move from one location to another in ballistic jumps (saccades) interposed with brief fixation periods of relative spatial stability, during which the visual system gathers information from the fixated area. Saccade peak-velocity and amplitude are lawfully related and quite similar from one individual to the next (Zuber, Stark, & Cook, 1965). And even during fixation periods, the eyes exhibit micro-movements that are believed to prevent image fading related to neural adaptation and may also play a role in attention mechanisms (Engbert & Kliegl, 2003; Hafed & Clark, 2002; Martinez-Conde & Macknik, 2007; Martinez-Conde, Macknik, & Hubel, 2004). So all normally-sighted individuals use the same basic program of eye-movement behavior regardless of the visual scene or task – saccades interposed with fixations, during which smaller eye-movements occur. However, it is clear that characteristics of the visual scene and task can affect the specifics of this program (e.g., frequency of saccades/fixations and how long they last) – finding a visual target will require more saccades of greater amplitude if the visual field is large with many stimuli than if it is small with few stimuli.

But do psychological factors also affect characteristics of eye-movement behavior? Just as individuals exhibit their own personality traits in overt behavior, do they also exhibit idiosyncratic eye-movement patterns while scanning visual scenes? – e.g., relatively frequent saccades of small amplitude? Only a few studies have investigated this question, but those that have do provide evidence of stable individual differences in several eye-movement metrics (Andrews & Coppola, 1999; Boot, Becic, & Kramer, 2009; Castelhano & Henderson, 2008; Rayner et al., 2007). These studies report substantial individual consistency in the relative values of fixation duration, saccade frequency, and saccade amplitude across a range of tasks and visual image content (e.g., some individuals consistently use more saccades than others to perform a task). But whether individuals exhibit idiosyncratic *profiles* of these and other eye-movement metrics has not been investigated – that is, the extent to which eye-movement measures vary systematically in relation to one another, and whether individuals exhibit

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idiosyncratic patterns in these relationships. That investigation is the primary focus of the present study.

We believe that the study of EmBP idiosyncrasies could contribute to a better understanding of oculomotor behavior as an operational system, and could also contribute to the development of new and existing models of such behavior (e.g., Reichle, Rayner, & Pollatsek, 2003). We know, for example, that eye movements correlate with shifts of visual attention. So could certain profiles of eye-movement behavior metrics (e.g., low or high fixation rates, short/long fixation durations, small/large saccade amplitudes, and so forth) be indicative of an individual's visual attention ability? In fact, there is already some evidence that this is true, in that ADHD-diagnosed individuals exhibit EmBP that are different than normal subjects' profiles (Karatekin, 2007; Karatekin & Asarnow, 1999; Karatekin, Bingham, & White, 2010; Karatekin, White, & Bingham, 2008; Munoz et al., 2003; Rommelse, Van der Stigchel, & Sergeant, 2008). The most consistent findings across studies indicate that ADHD subjects have difficulty controlling fixations and saccades and are more variable in their eye movement behavior – they have difficulty maintaining prolonged fixation, make more intrusive saccades, and make more errors on tasks requiring saccade inhibition.

The present study will examine whether EmBP idiosyncrasies also exist in normal subjects, and whether these idiosyncrasies are related to attentional function. Since individuals with clinical levels of attention deficit (AD) have difficulty maintaining prolonged fixation and inhibiting unwanted/intrusive saccades, we predicted that normal subjects in the present study with relatively high self-reported AD scores might exhibit more fixations of shorter duration than those with low scores, and also present more frequent and larger fixational eye-movements (e.g., microsaccades). We will examine individual differences in EmBP using six eye-movement metrics (Fixation Rate, Fixation Duration, Fixation Size, Saccade Amplitude, Micro-Saccade Rate, Micro-Saccade Amplitude). We expand on previous studies by adding three measures of fixational eye-movement to the investigation (Fixation Size,[1] Micro-Saccade rate and Amplitude), given their hypothesized role in visual attention mechanisms (Engbert & Kliegl, 2003; Hafed & Clark, 2002; Martinez-Conde & Macknik, 2007; Martinez-Conde, Macknik, & Hubel, 2004). We will look for consistent inter-metric correlations across tasks, determine whether individuals exhibit idiosyncratic patterns of these metrics, and determine whether such idiosyncrasies are related to a measure of attentional function.

2. Methods

2.1. Participants

Forty subjects (18 male, 22 female) between the ages of 18 and 33 participated in the experiment. All reported normal visual acuity and color vision. Individuals' *T*-scores on the attention/memory subscale of the Conners' Adult ADHD Rating instrument (Conners, Erhardt, & Sparrow, 1999) had $M = 52.5$, SD = 11.2. *T*-scores are based on age and gender norms provided with the Conner's instrument.

2.2. Materials and apparatus

The study was conducted in two separate rooms of a psychology department building on a university campus. One of the rooms contained a Tobii TX 300 EyeTracker used to measure various aspects of eye movement behavior (300 Hz gaze capture frequency). The device looks similar to a large computer display screen and the eyetracking hardware is not readily apparent to experimental participants. The device captures eye position remotely with cameras embedded in a module below the display screen that is used to present experimental stimuli (23 in. diagonal, 1920×1080 resolution, widescreen LCD). Viewing distance was 66 cm. Room illumination level (produced by overhead fluorescent lighting) was 455 lx.

We used a velocity–threshold fixation identification algorithm provided with the Tobii software to classify eye gaze points as either belonging to a fixation or a saccade (Komogortsev et al., 2010; Salvucci & Goldberg, 2000). Gaze samples were classified as belonging to a fixation if the velocity of the gaze-point movement was less than or equal to 30 deg/s, a value that typically provides good results for psychological research (Olsen & Matos, 2012). The eyetracking software provides a measure of the sampling accuracy rate for each participant (i.e., the percent of gaze samples that provided adequate information to identify the position of left and right eye gaze points). We used a threshold of 85% sampling accuracy to retain subject data for further analysis. Three subjects were excluded from further analysis based on this criterion.

The Conners' Adult ADHD rating scale was used to measure participants self-reported attention problems (Conners, Erhardt, & Sparrow, 1999). The inattention/memory scale was the measure of interest in our analysis. This scale presents behaviors or problems sometimes experienced by adults (e.g., "I'm absent minded in daily activities"). The subject is asked to rate "how much or how frequently" the behaviors describe themselves, using a Likert scale ("not at all", "once in a while", etc.).

Four visual tasks were chosen for the study (*Sustained-Fixation*, *Scan-Identify*, *Search*, and *Stroop*). We chose these tasks because they engaged various aspects of visual attention, including the ability to maintain focused attention (*Sustained-Fixation*), orient attention (*Scan-Identify*, *Search*), and selectively attend to stimulus attributes (*Stroop*). Fig. 1 presents monochrome illustration of these tasks. Displays were approximately 15° wide and 12° tall, although task-relevant stimuli occupied roughly two-thirds that area in the *Stroop* and *Sustained-Fixation* tasks. The *Scan-Identify* task involved reading numerical digits positioned along horizontal lines in an uneven pattern (Fig. 1A). Digits were black on a white background (153 cd/m^2), and measured approximately 0.34° in height. The *Search* task involved searching for the numbers 1 to 10 in consecutive order (Fig. 1B). Digits were approximately 0.5° in height. The *Stroop* task (Fig. 1C) required subjects to examine each of 15 colored words and identify the hue of the word letters. Each word had a hue that was incongruent with the color name. The hues were Red, Green, Yellow, and Blue (average luminance = 44.5 cd/m^2), and displayed on a black background (3.4 cd/m^2).[2] Lettering was approximately 1.1° in height. The *Sustained-Fixation* task (Fig. 1D) required subjects to fixate on a red dot (34.3 cd/m^2) that appeared at several locations on a black background. Dot diameter was 0.6°. There were four locations in the dot sequence and each dot remained on the screen for 3 s (temporal order of the sequence is numbered for illustration in 1D).

EmBP was represented by six eye-movement metrics (Fixation Rate, Fixation Duration, Saccade Amplitude, Fixation Size, Micro-Saccade Rate, and Micro-Saccade Amplitude). Fixation Rate was measured as the number of fixations per second. Likewise, Micro-Saccade Rate was measured as number of Micro-Saccades per second. Our algorithm for automated detection of microsaccades closely follows that developed by Martinez-Conde,

[1] Fixation size is a new metric of fixational eye-movement amplitude. Details of this metric will be presented in Section 2 of this report.

[2] LCD luminance values are known to vary to some degree with viewing angle, so stated luminance levels are best approximations.