## Title

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# Measuring the separate effects of practice and fatigue on eye movements during visual search

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**Abstract**

Two experiments were conducted to examine how time-on-task (i.e., practice and fatigue) influences eye movements during visual search. In Experiment 1, we examined how practice influences eye movements during an extended visual search task. Results replicate the findings that over the course of a visual search task, performance improves and fixation duration increases. Yet changes in fixation duration did not correlate with changes in search performance. In Experiment 2, we examined how fatigue influences eye movements during an extended visual search task. To manipulate fatigue, participants either did or did not receive breaks. Those who did not receive breaks replicated the findings in Experiment 1. Critically, participants who did receive breaks showed no increase in fixation duration over the course of the visual search task. These results indicate that the increase in fixation duration with time-on-task reflects fatigue, and that this measure of fatigue can be derived independent of measures of performance improvements, such as shorter response times.

**Keywords:** Visual Search, Attention, Practice, Fatigue, Eye Movements.

Previous research (Horowitz, Cade, Wolfe & Czeisler, 2003; Wolfe et al, 2007) has shown that after long passages of time, critical items are missed during visual search. Given that many studies have shown that fatigue negatively impacts the ability to allocate attention across a broad spectrum of tasks (Casagrande, Violani, Curcio & Bertini, 1997; Dawson & Reid, 1997; Drumer & Dinges, 2005; Fairclough & Graham, 1999; Lyznicki, Doege, Davis & Williams, 1998; Marcus & Loughlin, 1996; Williamson & Feyer, 2000), it is reasonable to think that the fatigue which arises over time while engaging on a task contributes to search performance failures over time. Fatigue can be manifested in a number of different ways. For example, fatigue is considered to result from working (e.g., Winwood, Winefield, & Lushington, 2006), mental stress (Baumeister, 2002), psychopathology (Berrios, 1990), boredom (Wyatt & Langdon, 1937), disease (Whitehead, 2009), and lack of sleep (Durmer, & Dinges, 2005). In the present context, we refer to the fatigue that is associated with time-on-task (e.g., Neri, et al., 2002; Stern, et al., 1993; Wilkinson, 1961). Pinpointing the role of fatigue on search performance is inherently challenging, given that a) the negative effect of fatigue overlaps with the positive effect of practice on a task, and b) the same behavioural measures (e.g., response time, RT) are used to assess both the positive and negative effects of time on task. Further, several studies have found that RT measures are actually insensitive to fatigue (Baulk, Reyner & Horne, 2001; Gillberg, Kecklund & Akerstedt, 1996; Milosevic, 1997). Utilizing the fact that fatigue appears to influence oculomotor control (Bocca & Denise, 2006; De Gennaro, Ferrara, Urbani & Bertini, 2000; Galley 1989; Galley & Galley, 1998; Hoffman, 1946; Luckiesh & Moss, 1937; Morris & Miller 1996; Saito, 1992; Schleicher, Galley, Briest & Galley, 2008; Sirevaag & Stern 2000; Stern, Boyer, & Schroeder, 1994; Summala, Häkkänen, Mikkola, & Sinkkonen, 1999), and could lead to an increase in fixation duration, the present paper investigated the intriguing possibility that fixation duration could provide an index of fatigue over time that is separable from the beneficial effects of practice on a task.

To achieve this aim, in two experiments the eye movements and performance of individuals were monitored as they performed a visual search task. Experiment 1 confirmed that changes in fixation duration are not correlated with the improvements in search that come from practice. Experiment 2 manipulated levels of fatigue, and showed that as fatigue levels increased, so did fixation duration, and that this could be separated and measured reliably from the positive effects that practice has on search performance. Collectively these data provide evidence that eye movements can be used as an indicator of fatigue that is independent of other performance changes, in particular, the positive performance changes that accompany practice.

## Experiment 1

Participants performed a standard attentionally demanding visual search task, whereby search time increases with set size, and indicating that a target is absent takes longer than reporting a target's presence (Wolfe, 1998). An SR Research EyeLink 1000 desktop mount eye tracking system measured fixation duration.

### Method

**Participants** Twelve undergraduates (8 female) received course credit for participating.

**Design** A 2 (Target presence: present vs. absent) x 2 (Set size: 7 vs. 14 items) x 12 (Block: 1-12) within design was used.

**Stimuli** The stimulus displays were presented on a 24-inch monitor set at a resolution of 1920 by 1200, with participants seated 80 cm from the screen. The visual search display consisted of target and distractor letters in an imaginary 6 x 6 grid, with cell-centres separated by 170 pixels horizontally and 128 pixels vertically. The only letters used as targets were "E", "K", "P", and "Z". Target letters never appeared as distractors in the visual search displays. All letters were presented in 36-point Lucida Console font, measuring approximately 0.6 cm horizontally and 1.2 cm vertically, subtending 0.6 degrees of visual angle.

**Procedure** Each participant received 600 trials which were divided into 12 blocks of 50 trials. Eye tracking calibration was conducted before each block. Additionally, drift correction was conducted every 10 trials. Each target letter appeared in 25% of the target present displays. The displays were randomized for each participant. The visual search task consisted of the search for one of the target letters amongst either 6 or 13 distractor letters. Trials began with a 500 ms display indicating the target to be searched for on that trial, followed by a blank screen for 200 ms and then the search display. The participants were instructed to search for the target letter and press the right button on a gamepad if the target was present and the left button if the target was absent. The display remained on the screen until a response was made, at which point a blank screen was presented for 200 ms. The experiment took approximately 40 minutes.

### Results & Discussion

Participants were encouraged to familiarize themselves with the task for the first 12 trials of the study, so those trials were removed from analysis. If the pupil was undetectable at any point during a trial (this includes blinks) then the trial was removed (8.4% of the trials). An error analysis was conducted on the remaining trials on which errors occurred (4.5%). The remaining analyses were conducted on the correct responses only. Each measure was analyzed using an Analysis of variance (ANOVA) with Target Presence (present vs. absent), Set Size (7 vs. 14 items), and Block (1 to 12) as within participant factors. We report all significant main effects and interactions. Because the focus of the study relates directly to time-on-task, we focus on the main effect of block and its interactions with other variables.

**Performance** Change in RT is plotted as a function of block (i.e., practice) in Figure 1. For RT, there was a main effect of Target Presence, $F(1, 11) = 84.29$, $MSE = 809646.70$, $p < .001$, whereby responses were shorter on target present trials than target absent trials. There was a main effect of Set Size, $F(1,11) = 190.71$, $MSE = 303531.15$, $p < .001$, with responses shorter on set size 7 trials than set size 14 trials. In addition, there was a Target Presence by Set Size interaction, $F(1, 11) = 103.96$, $MSE = 147848.77$, $p < .001$, indicating that the effect of target presence was greater on set size 14 trials than set size 7 trials. Critically, there was a main effect of Block, $F(11, 121) = 5.18$, $MSE = 31649.60$, $p < .001$, reflecting that responses became faster as block increased. No other main effects or interactions were significant. For errors, there was a main effect of Target Presence, $F(1, 11) = 28.02$, $MSE = 0.01$, $p < .001$, whereby fewer errors were made on target absent than target present trials. No other main effects or interactions were significant.

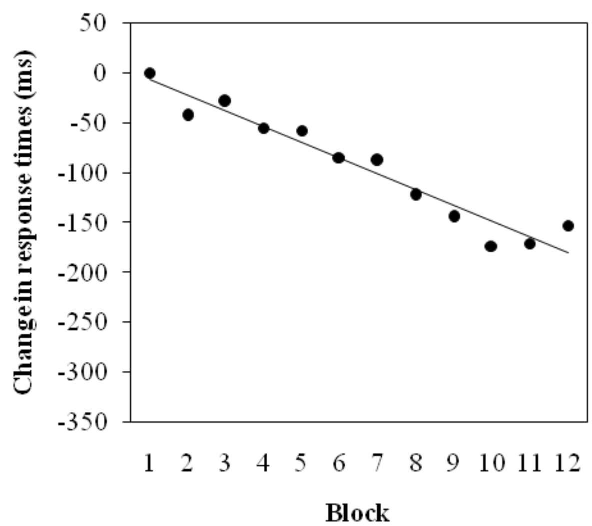


Figure 1: Change in RT as a function of Block relative to the first Block in Experiment 1.

**Eye Movements** Change in fixation duration is plotted as a function of block (time-on-task) in Figure 2. Measurement of fixation duration revealed a main effect of Target Presence, $F(1, 11) = 40.60$, $MSE = 1403.60$, $p < .001$, indicating that fixation durations were shorter on target absent than target present trials. There was a main effect of Set Size, $F(1,11) = 8.40$, $MSE = 350.20$, $p < .02$, with fixation durations being shorter on set size 14 trials than on set size 7 trials. Note that the average RT on trials without targets and with 14 items was approximately 2-3 seconds, and our understanding of fatigue does not operate on this time scale. In other words, fatigue gradually increases throughout a task and, as such, is not measured over the course of a single trial. Critically, there was a main effect of Block, $F(11, 110) = 3.10$, $MSE = 261.40$, $p < .002$, indicating that participants' average fixation duration increased as block increased.

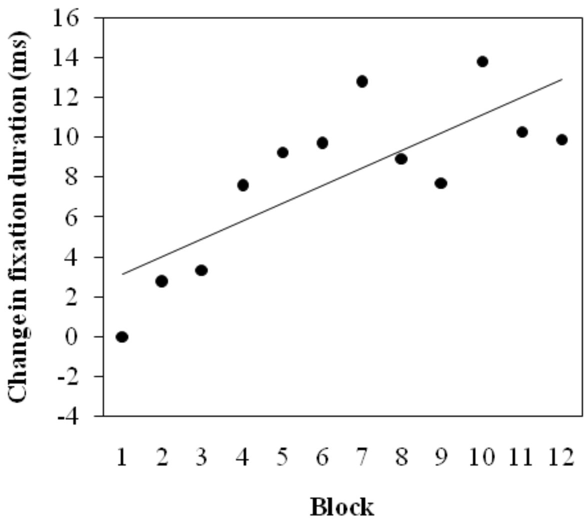


Figure 2: Change in Fixation Duration as a function of Block relative to the first Block in Experiment 1.

**Relation Between Performance and Eye Movements** Finally, we calculated the change in both fixation duration and RT as a function of block for each participant. We then correlated these measures to examine the relationship between changes in RT and fixation duration over time. There was no correlation between the change in RT and the change in fixation duration as a function time on task, $r(12) = 0.37$, $p = 0.234$, demonstrating that the positive effect of practice on visual search is not driving the change in fixation duration[1]. Our working hypothesis is that this increase in fixation duration reflects an increase in fatigue – a factor that increases with time-on-task, but is qualitatively distinct from those factors that benefit from time-on-task and lead to a performance improvement. Experiment 2 put this interpretation to a direct test.

## Experiment 2

As in Experiment 1, participants performed a standard attentionally demanding visual search task while their eye movements were monitored. Critically, half of the subjects received a three-minute break between each block of trials and the other half of the subjects did not. Fatigue is associated with time on task (Wilkinson, 1961; 1963; 1965). As time-on-task increases the effect of fatigue on performance also increases. Providing subjects with a break reduces the amount of fatigue experienced throughout the task (Neri, et al., 2002; Stern, et al., 1993). If changes in fixation duration are related to fatigue, then we would not expect fixation duration to increase as a function of block in the Break group. However, in the No Break group, we would expect fixation duration to increase as a function of block as it did in Experiment 1.

### Method

**Participants** Thirty-two undergraduate students (14 female) received course credit for participating.

**Design** A 2 (Break condition: breaks vs. no breaks) x 2 (Target presence: present vs. absent) x 2 (Set size: 7 items vs. 14 items) x 12 (Block: 1-12) mixed design was used. The break condition was manipulated between participants; target presence, set size and block were manipulated within participants.

**Stimuli and Procedure** The stimuli and procedure were the same as those used in Experiment 1, except that each participant now received 576 trials which were divided into 12 blocks of 48 trials. The drift correction was now conducted every 12 trials. In addition, half of the participants now received breaks and half did not. Participants in the break condition received eleven 3 minute breaks, one at the end of each block of trials. Participants in the no break condition did not receive breaks throughout the task. The experiment was approximately 40 minutes in the no break condition and 75 minutes in the break condition.

### Results & Discussion

Analysis was preceded by the same trial removal procedure used in Experiment 1 resulting in the removal of the first 12 trials and trials on which the pupil was undetectable (9.5%) or errors occurred (3.1%). Each measure was analyzed using a mixed ANOVA with Breaks (No Breaks vs. Breaks) as a between participant factor and Target Presence (present vs. absent), Set Size (7 vs. 14 items), and Block (1 to 12) as within participant factors.

**Performance** Change in RTs for the break and no break conditions are plotted as a function of block in Figure 3. For RT, there was a main effect of Target Presence, $F(1, 30) = 219.84$, $MSE = 836634.27$, $p < .001$, and Set Size, $F(1, 30) = 447.56$, $MSE = 367483.96$, $p < .001$. In addition, there was a Target Presence by Set Size interaction, $F(1, 30) = 255.93$, $MSE = 128222.02$, $p < .001$, which indicates that search was more efficient when the target was present than when it was absent. Critically, there was a main effect of Block $F(11, 330) = 12.94$, $MSE = 78443.64$, $p < .001$, whereby search became more efficient, that is, the time to determine whether a target was present or absent, became faster as block increased. This finding replicated the practice effect on performance observed in Experiment 1. There was

[1] We speculated that there may not be sufficient power to a detect a significant relationship in the present analysis. In Experiment 2, we report a follow-up analysis that pools the data from Experiment 1 and 2. This result is convergent with the present conclusion.

also a Block by Set Size interaction F(11, 330) = 4.88, MSE = 18439.20, p < .001, which indicates that search became more efficient over time. No other main effects or interactions were significant. For errors, there was a main effect of Target Presence, F(1, 30) = 43.16, MSE = 166.03, p < .001, and Set Size, F(1, 30) = 16.14, MSE = 29.59, p < .001. In addition, there was a Target Presence by Set Size interaction, F(1, 30) = 14.15, MSE = 30.30, p < .001, indicating that the effect of target presence was greater on set size 14 trials than set size 7 trials. No other main effects or interactions were significant.

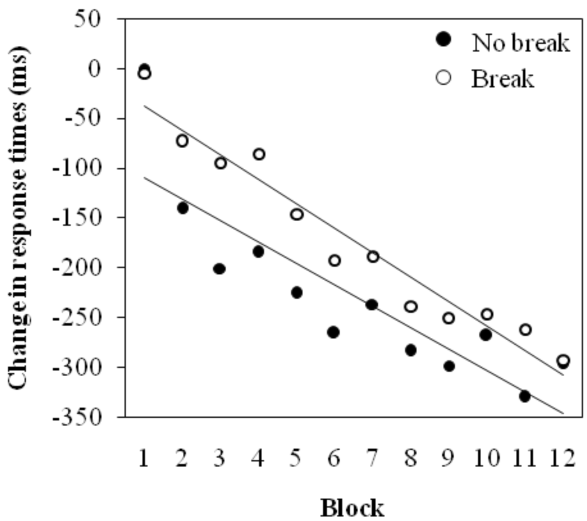


Figure 3: Change in RT as a function of Block relative to the first Block in Experiment 2.

**Eye Movements** Change in fixation duration is plotted as a function of block (time-on-task) in Figure 4. Measurement of fixation duration revealed a main effect of Target Presence, F(1, 30) = 132.73, MSE = 1739.87, p < .001, and a main effect of Break, F(1, 31) = 2.88, MSE = 14847.77, p < 0.01, such that fixation durations were shorter in the no break condition than in the break condition. There was a Target Presence by Set Size interaction, F(1, 30) = 28.84, MSE = 197.40, p < .001, and a Block by Target Presence interaction, F(11, 330) = 4.09, MSE = 161.66, p < .001, Most critically, there was a main effect of Block, F(11, 330) = 2.41, MSE = 289.61, p < 0.007, whereby participants' average fixation duration increased as block increased and a Block by Break interaction, F(11, 330) = 1.87, MSE = 289.61, p < 0.042. No other main effects or interactions were significant.

To further assess the interaction of Block with Break, we calculated the slope relating Fixation Duration to Block. The effect of block was larger in the no break (1.14) condition than in the break condition (0.08), $t(30) = 2.57$, $p < .015$. The slopes were significantly different from zero in the no break condition, $t(15) = 3.43$, $p < .005$, but not in the break condition, $t(15) = .32$, $p = .752$. This interaction confirms our hypothesis that the increases in fixation duration observed in Experiment 1, and in the No Break group in Experiment 2, reflect increasing fatigue as a function of increased time-on-task[2].

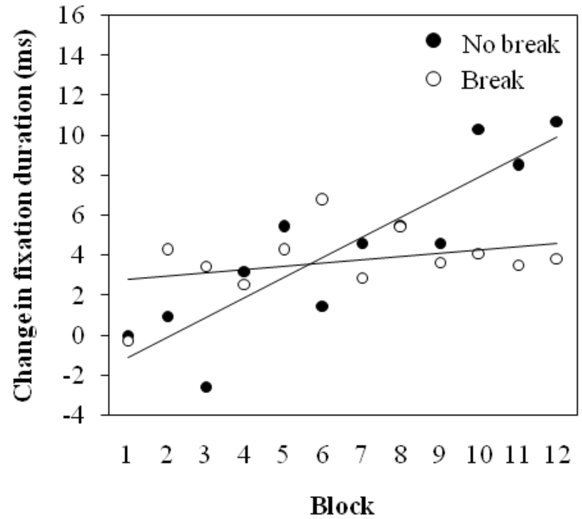


Figure 4: Change in Fixation Duration as a function of Block relative to the first Block in Experiment 2.

**Relation Between Performance and Eye Movements in Experiment 1 and 2** Our argument that the increase in fixation duration reflects an increase in fatigue over the course of the task was based in part on the absence of a correlation between the changes in fixation duration and RT as a function of time observed in Experiment 1. Experiment 2 provides strong and convergent support for this argument by dissociating fixation duration and RT (i.e., a Block x Break interaction in fixation duration, and the lack of this interaction in RT). Finally, to increase the power of the original analysis in Experiment 1 we pooled the data from Experiment 1 and the no break condition of Experiment 2. There was a significant correlation, $r(28) = 0.386$, $p < 0.04$, demonstrating that improvements in RT over time are related to decreases in fixation duration over time in individual subjects. As such, the *positive* effect of practice on visual search (i.e., shorter RTs) is not driving the increase in fixation duration, as individuals who improved the least or became slower over time also showed the greatest increase in fixation duration over the course of the task. This finding supports the notion that an increase in fixation duration is related to an increase in fatigue that results from an increase in time on task.

[2] We did conduct a parallel set of analyzes to those reported using fixation number, saccadic amplitude, blinks, and saccadic duration. There was no effect of block or the critical block by break interaction on saccadic amplitude or saccadic duration. However, we did find an effect of block on fixation number such that fixation number decreased over the course of the task in both Experiment 1 and in both break conditions in Experiment 2. In Experiment 2, we did not find an interaction between Break and Block. Taken together, these data suggest that decreases in fixation frequency over time are not indexing the negative effect of fatigue, but rather may be indexing the positive effect of practice

## General Discussion

Many everyday tasks require looking for objects over extended periods of time. For example, security officers may be required to conduct searches for the larger part of the workday. Given that performing even the most basic task for an extended period of time can lead to fatigue, and ultimately performance failures (Dawson & Reid, 1997; Drumer & Dinges, 2005; Williamson & Feyer, 2000), the present study provides a measurement tool for assessing this change in state even when it is co-occurring with the positive effects of practice.

There are a number of reasons that fatigue might influence fixation duration. The increase in fixation duration may reflect an oculomotor disengage deficit. Bocca and Denise (2006) demonstrated that the effect of fatigue on saccadic latency was more pronounced when the fixation remained on the screen than when the fixation was removed prior to appearance of an eye movement target (see also Versace et al., 2006). This pattern of results has typically been interpreted as reflecting a difficulty in disengaging the oculomotor system from fixation (e.g., Kingstone & Klein, 1993). Further, there is evidence that damage to the parietal lobe leads to problems disengaging attention (Olk, Hildebrandt & Kingstone, 2009) and fatigue is known to disrupt parietal lobe function. Thus, fatigue may influence the ability to initiate an eye movement.

Another possibility is that fatigue influences the decision to move the eyes from one location to another. In the present context, the decision to move from one location to another is dependent on the decision that the target is not at the currently attended location. The ability to make this decision may be disrupted by fatigue induced as time-on-task increases. For example, a number of studies have demonstrated a selective impairment of frontal lobe function when an individual is fatigued (e.g., Harrison and Horne, 2000; Jones & Harrison, 2001). The frontal lobe has also been associated with goal maintenance (e.g., Miller & Cohen, 2001). Thus, activation of the goal "find the letter X" may decrease when individuals become fatigued as time-on-task increases. This decreased goal activation may lead to lapses resulting in longer fixation durations. Lapses have long been associated with fatigue and are thought to arise because of transient disruptions in cognitive control (e.g., Lim & Dinges, 2008).

One important goal of future research will be to tease apart which of these mechanisms, or combination of mechanisms, drive the oculomotor mechanisms (e.g., fixation duration) that are sensitive to the effects of fatigue in search, even when it overlaps with the positive effects of practice on a task. This is a finding of potentially great importance because it means that one could use fixation duration as a means to detect the presence of fatigue well before its inevitable negative effects begin to override the positive benefits of time on task. For instance, security guards at airports might be performing their examinations of luggage x-rays quickly and effectively, but measures of fixation duration could determine that the searcher is growing fatigued and a break would be well advised. Similarly, it is clear that driving requires one to constantly be searching the visual world and yet the dangers of fatigue are no less profound. In principle measures of fixation duration could be obtained noninvasively while one is driving, and when reliable increases in fixation duration are detected, a driver could be encouraged to take a small restbreak at the next opportunity, with the potential that lives on the roadways could be saved. In sum, while the ability to sustain attention in both fatigued and non-fatigued individuals has attracted a great deal of research recently (e.g., Lim and Dinges, 2008), the relations between indices of sustained attention and spatial attention (i.e., eye movements) have received little consideration. This is surprising given the importance of vision to the performance of everyday tasks. The present work represents an initial and significant step forward in understanding how oculomotor measures of sustained attention vis-a-vis fixation duration can be used to detect the presence of observer fatigue independent of the beneficial effects that time-on-task can have on visual search performance.

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