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The reliability of eyetracking to assess attentional bias to threatening words in healthy individuals

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Title: The reliability of eye tracking to assess attentional bias to threatening words in healthy individuals

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Suggested Running Read: Reliability of eye tracking to assess attentional bias

Abstract

Eye tracking is commonly used to investigate attentional bias. Whilst some studies have investigated the internal consistency of eye tracking, data on the test-retest and agreement of eye tracking to investigate attentional bias is scarce. This study reports the test-retest reliability, measurement error and internal consistency of twelve commonly used outcome measures thought to reflect the different components of attentional bias: overall attention, early attention and late attention. Healthy participants completed a preferential looking, eye tracking task that involved the presentation of threatening (sensory words, general threat words, affective words) and non-threatening words. We used intraclass correlation coefficients (ICCs) to measure test-retest reliability (ICC > .70 = adequate reliability). ICCs(2,1) ranged from -.31 to .71. Reliability varied according to the outcome measure and threat word category. Sensory words had a lower mean ICC (.08) than the affective words (.32), and the general threat words (.29). A longer exposure time was associated with higher test-retest reliability. All the outcome measures, except second run dwell time, demonstrated low measurement error (<6%). Most outcome measures reported high internal consistency (α > .93). Recommendations for improving the reliability of eye tracking tasks in future research are discussed.

Keywords: eye tracking, reliability, attentional bias, preferential looking, threat

Introduction

Eye tracking is increasingly being used to investigate attentional bias (Armstrong & Olatunji, 2012; Liossi, Schoth, Godwin, & Liversedge, 2014; Mogg, Bradley, Field, & De Houwer, 2003). Compared to traditional reaction time based methods of attentional bias such as the dot probe task, eye tracking is proposed to provide a more direct, and therefore superior, measure of sensory processing (Armstrong & Olatunji, 2012; Toh, Rossell, & Castle, 2011). However as few reports have been published on the reliability of eye tracking it is unknown whether study results are valid. This is because the reliability of a measure can influence Type II error rates, effect sizes, and confidence intervals (Kopriva & Shaw, 1991; Loken & Gelman, 2017; Meyer, 2010).

Attentional Bias

Attentional bias describes the preferential allocation of cognitive resources to the detection of salient stimuli (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013). Attentional bias to threat stimuli has been identified in the development and maintenance of clinical conditions such as addiction, anxiety, depression and chronic pain (Sharpe, Haggman, Nicholas, Dear, & Refshauge, 2014; White, Suway, Pine, Bar-Haim, & Fox, 2011). Recently, attentional bias modification training has been found to reduce symptoms of affective and pain disorders (Amir, Beard, Burns, & Bomyea, 2009; Amir, Weber, Beard, Bomyea, & Taylor, 2008; Sharpe et al., 2012).

Models of attentional bias, such as the 'vigilance-avoidance' model (Mogg, Bradley, Miles, & Dixon, 2004) and 'threat interpretation' model (Todd et al., 2015), consider attentional bias to be dynamic; attentional bias may shift towards or away from a stimulus during the stimulus exposure. For example, the vigilance-avoidance model posits that

individuals may attend to a threat stimulus during initial exposure (vigilance) but then after detection, avoid the threat stimulus (avoidance) (Mogg et al., 2004). These models incorporate a temporal component of processing, broadly categorised into overall, early and late processing. To investigate such models, methods that can consistently distinguish between the temporal components of attentional processing are needed.

Eye Tracking

Eye tracking continuously measures eye movements to stimuli presented on either a computer screen or mobile head centred video device. Pre-specified spatial (e.g. displacement) and temporal (e.g. velocity and acceleration) eye movement parameters are used to derive "fixations" and "saccades". Fixation-based measures can be categorised according to the component of attention they are proposed to measure: overall, early, or late. Overall attention combines early and late stage processing and reflects the viewing pattern across the total stimulus duration. For example, if stimuli are presented for 4000ms, the total dwell time towards the salient stimulus is considered an indicator of overall attention. Early attention reflects the initial viewing pattern when stimuli are first presented and has been used to indicate initial vigilance, which may be important in threat detection (Armstrong & Olatunji, 2012). Examples include; location of the first fixation, first fixation latency, and duration of the first fixation to a salient stimulus. Late attention reflects the viewing pattern that occurs after the initial viewing pattern and is thought to reflect rumination or maintenance, which are important in theories of depression (Donaldson, Lam, & Mathews, 2007). Examples of late attention outcome measures are; second or last run dwell times, and dwell time for the 2nd half of the stimulus duration.

Eye tracking has been used to investigate attentional bias in clinical conditions such as depression (Armstrong & Olatunji, 2012), anxiety (Armstrong & Olatunji, 2012), addictive disorders (Mogg et al., 2003), obesity (Gao et al., 2011), post-traumatic stress disorder (Felmingham, Rennie, Manor, & Bryant, 2011), and pain (Fashler & Katz, 2014; Yang, Jackson, & Chen, 2013). Distinguishing the temporal components allows researchers to more clearly define the role of attentional bias in these clinical conditions. For example, Duque (2015) found that participants with major depressive disorder had an attentional bias to sad faces for maintenance indices (late processing) such as total fixation time, but not for orienting (early processing) attention indices.

There is considerable variability on the tasks and procedural variables used in eye tracking research (Radach & Kennedy, 2004). For example, tasks (e.g. preferential looking task, visual search tasks, dot probe tasks), outcome measures (e.g. first fixation latency, percentage of initial fixations, average visit duration) and stimuli (e.g. words, images, faces) are common (Fashler & Katz, 2014; Felmingham et al., 2011; Yang, Jackson, Gao, & Chen, 2012). However the reliability of attentional bias tasks has been questioned (Rodebaugh et al., 2016b), and good quality information on the reliability of procedural variables will help inform which tasks, outcome measures, and stimuli to use in future research studies.

Reliability

It is important that paradigms and procedural variables, such as those used to investigate attentional bias, produce measurements that are reliable. Poor reliability has statistical and conceptual implications. It has been demonstrated, for example, that effect

sizes can vary depending on the sample size (Loken & Gelman, 2017), and statistical

power is reduced as the reliability of a task decreases (Meyer, 2010). Conceptually, it is

difficult to reproduce study findings if tasks and procedural variables are not reliable.

Conclusions from experiments with poor reliability are therefore questionable (Loken &

Gelman, 2017).

As there is some variability in descriptions of reliability, we used the taxonomy

described by Mokkink et al. (2010). Reliability is comprised of three measurement

properties; test-retest reliability, measurement error and internal consistency (Mokkink et

al., 2010). These three measurement properties reflect conceptually different aspects of

reliability and should all be considered when investigating reliability (Mokkink et al., 2010;

Scholtes, Terwee, & Poolman, 2011). A minimum of two testing sessions is required to

assess test-retest reliability and agreement, whereas internal consistency can be evaluated

using data from a single testing session.

Test-retest reliability indicates how well a task can distinguish between participants

with reference to the consistency between measurements (de Vet, Terwee, Knol, & Bouter,

2006a). Both the consistency of results between measurements and the participant variance

are used to calculate test-retest reliability, i.e. did participants all score the same or was

there adequate variability in the results to distinguish participants from each other. The

preferred method for assessing test-retest reliability is the Intraclass Correlation Coefficient

(ICC). ICCs vary between 0 and 1, although theoretically it is possible to report values lower

than 0. Higher numbers reflect stronger evidence of test- retest reliability (Weir, 2005).

Measurement error reflects the consistency of results between measurements, i.e.

how similar the results are between testing sessions (de Vet et al., 2006a). Unlike test-retest

reliability the variance between participants is not considered when calculating

measurement error (Kottner & Streiner, 2011). Measurement error is reported in the

same unit as the task. Low measurement error is preferred.

Low measurement error (i.e. consistent results between testing sessions), and poor

test-retest reliability (i.e. unable to distinguish participants) arise when there is too little

variance between participants (their scores are too similar). For example, if newborn human

babies were weighed twice on the same day using scales designed for newborn elephants all

the human babies would have consistent scores between measurements (low measurement

error), however the scores would not be able to distinguish between the human babies due

to the low variance in scores (poor test-retest reliability). Test- retest reliability is therefore

considered more beneficial for discriminative testing, i.e. when aiming to differentiate

participants based on a set of scores from a certain task, as in cross sectional studies.

Measurement error is preferred for evaluative testing, when testing participants over time

and measuring within subject change. Variation in participant scores is regarded as less

important for evaluative testing. When investigating attentional bias tasks procedural

variables are required that produce scores that can both accurately discriminate between

participants (discriminative testing indicated by test-retest reliability), and accurately

measure change over time for individual participants (evaluative testing indicated by

agreement) (Guyatt, Walter, & Norman, 1987).

Internal consistency indicates how subjects respond to individual items on a task, i.e

the homogeneity of the items on a scale (interrelatedness) (Streiner, 2003c). For example,

when investigating attentional bias to threat related anxiety, participants would be

expected to view each threat related word in a similar manner. A high level of internal

consistency provides confidence that the interpretation of the composite score is an accurate measure of the underlying construct being investigated. Cronbach's alpha is the preferred method for analysing internal consistency, as it considers the mean of all possible splits. Split half reliability tends to underestimate reliability by splitting a scale in half and depending on how the scale is split returns different reliability (Streiner, 2003c).

Eye tracking tasks that measure attentional bias should be able to discriminate between people (high test-test reliability), have consistent scores on repeated testing (low measurement error) and high interrelatedness of items (high internal consistency) (Kottner & Streiner, 2011; Streiner, 2003b).

Previous Research

Waechter, Nelson, Wright, Hyatt, and Oakman (2014) examined the internal consistency of eye tracking within a dot probe paradigm in university students with high and low social anxiety. Anger, disgust and happy facial images were paired with calm or neutral facial images using a 5000ms exposure time. Reliability coefficients for early attention were low (e.g. proportion of first fixation to angry faces: α = -2.18). Conversely eye movement indices using the full stimulus exposure (overall attention) had excellent reliability (e.g. proportion of viewing time to angry faces 0-5000ms: α = .94). Waechter et al. (2014) concluded that more research was needed to establish reliable methods to assess attentional bias.

Price et al. (2015) reported the test-retest reliability of eye tracking within a dot probe paradigm using fearful and neutral facial images and a 2000ms exposure time. Single

and average ICC measures were reported for healthy children (aged 9-13 years) at five time points over a 14-week period. ICC scores for all trials varied between -.03 to .55 depending on the data filtering process (e.g. excluding reaction times <300ms and >2500ms and ±3 SDs from individual's session means) and the reliability statistic used to interpret the results (i.e. single or average ICC). Importantly none of the ICCs were above a standard threshold for acceptability (i.e. ICC > .70).

Lazarov, Abend, and Bar-Haim (2016) tested the internal consistency and test-retest reliability of eye tracking within a free viewing task using sixteen simultaneously presented facial images for 6000ms (half the faces displayed disgusted expressions and half were neutral). Participants were 20 university students with high social anxiety, and 20 university students with low social anxiety. Measures of early attentional bias (latency to first fixation, first fixation location, first fixation dwell time) and overall attention (total dwell time) were reported. Cronbach's alpha scores, representing internal consistency, for overall measures of attentional bias were high, ranging from .89 to .95. One week test- retest reliability for overall attentional bias using Pearson's correlation coefficients ranged from .62 to .68. Test-retest reliability for early measures of attentional bias were lower than the measures of overall attention, ranging from .06 to .08.

Data from these studies suggests that measures of early attention, or measures that use less of the available stimulus presentation time, may have lower internal consistency and poorer test- retest reliability than measures that use more of the available stimulus duration.

There are no published data on the reliability of using words as stimuli in attentional bias research using eye tracking. This is important as a systematic review found that words are the most common stimuli in attentional bias tasks (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van, 2007).

There is also a lack of published data on the agreement of eye tracking when used to investigate attentional bias. Evidence from one measurement property of reliability does not provide evidence for another measurement property (Guyatt et al., 1987). For example, test-retest reliability and internal consistency are not suitable measures of reliability for evaluative studies, i.e. comparing within subject measures over time. Agreement is the measurement property that indicates whether a measurement tool is appropriate for determining longitudinal changes (de Vet et al., 2006a; Guyatt et al., 1987). An understanding of all three measurement properties of reliability allows researchers to decide for what purpose, between subjects (discriminative) or within subject (evaluative) testing, a tool is appropriate.

Healthy participants are commonly used as a comparison group in attentional bias studies. No studies have reported reliability data on healthy adult participants using eye tracking with words as stimuli. Reliability is known to be specific to the population in which it has been tested, therefore it is possible that the measurement properties of eye tracking may vary between clinical populations and healthy participants (Lakes, 2013). Compared with healthy control participants, greater variation is often found in data obtained from clinical populations (Bartko, 1991). If measurement error is stable then increased between-subject variance will increase test-retest reliability, whereas decreased between-subject variance may decrease test-retest reliability. For example, Farzin, Scaggs, Hervey, Berry-

Kravis, and Hessl (2011) investigated the reliability of gaze aversion, to different facial features, in participants with Fragile X syndrome (FXS) and healthy controls. Test retest reliability for the proportion of time spent looking at the mouth was higher (ICC= .97) in the FXS cohort than it was in the healthy controls (ICC = .63). Farzin et al. (2011) noted the reduced between-subject variance in the healthy controls may explain the lower ICC values (test-retest reliability). Accurately investigating between group differences requires adequate reliability in both clinical populations and healthy controls.

The Current Study

The primary aim of this study was to assess the reliability of eye tracking when used to investigate attentional bias to threat related words in healthy participants. Reliability will be assessed using test-retest reliability, measured with ICC(2,1), measurement error, measured with SEM, and internal consistency measured with Cronbach's α.

Methods
Study Design

We used an observational, test-retest design. Healthy participants completed an identical preferential looking task on two occasions. A methodological protocol for the study was published to the completion of data collection (Open Science Framework, MT3K8). Deviations from the protocol are noted in this paper. Ethics approval was obtained from the University of New South Wales Human Research Ethics Committee (HC14240).

Participants

Healthy adult participants were recruited from the Sydney metropolitan area. Participants were included in the study if they were: 18-75 years old, had good level of English proficiency, and had normal or corrected normal vision.

English proficiency was assessed using three questions from the Language Experience and Proficiency Questionnaire. Participants were asked to select, on a scale from zero to ten, their level of proficiency in speaking, understanding and reading English. A minimum score of seven, which is regarded as "good," was required for participants to be included (Marian, Blumenfeld, & Kaushanskaya, 2007). We excluded participants with poor English proficiency because fixations may be unrelated to the threat value of the word. Global measures of self-report proficiency are good indicators of actual performance on specific measures of language ability (Marian et al., 2007).

Participants were excluded if they were currently reporting pain in any body region, previous pain condition that lasted more than six months, pain in any body region that had lasted more than 72 hours any time during the past three months.

Materials

Apparatus

An Eyelink 1000 eye tracker, (V4.56; SR Research; Ontario, Canada) with remote camera upgrade, desktop mount, 16mm lens, and target sticker was used to record

monocular eye movements from the right eye at 500Hz. Stimuli were displayed on a

HP Compaq LA2205 wide LCD monitor with a 1680 X 1050 resolution, 32 bits per pixel,

and a refresh rate of 60Hz. The preferential looking task was programmed with Experiment

Builder (V1.10.1241; SR-Research; Ontario, Canada). A 5-point calibration procedure was

used and accepted when the average calibration error was less than 1° of visual angle. We

used a 5-point calibration, instead of the default 9-point calibration, as the stimuli did not

extend to the corners of the display. This is in keeping with previous other eye tracking

studies that use remote eye trackers with no fixed head mount (Lazarov et al., 2016). All

stimuli were presented in white on a black background.

Procedure

Testing took place at Neuroscience Research Australia. Each participant attended

one 90-minute session. Upon completion of the task, participants completed a demographic

questionnaire along with the short-form version of the Depression Anxiety and Stress scales

(Lovibond & Lovibond, 1995), and the Pain Catastrophising Scale (Sullivan, Bishop, & Pivik,

1995). Participants were given 20 minutes to complete the questionnaires, followed by a

compulsory 10-minute wash out period, during which time they were seated quietly, before

the task was conducted a second time (re-test).

Preferential looking task

Preferential looking tasks display two competing stimuli and participants are instructed to view stimuli stimuli as they wish. We used a preferential looking task, instead of the more traditional dot probe task, as previous research suggests the dot probe task is not reliable (Rodebaugh et al., 2016a; Schmukle, 2005). The test-retest reliability and agreement for words is unknown when using eye tracking.

The preferential looking task consisted of eight practice trials and 48 active trials. Each trial consisted of three sequentially presented still screens. The first screen displayed a fixation cross (font: Times New Roman normal; size: 90; location: x = 840, y = 525 [centre of screen]). Participants were instructed to fix their gaze on the middle of the cross. A researcher sitting in an adjacent room monitored the participants' gaze. After a stable fixation had been made on the cross for 2000ms the researcher manually progressed the trial to the next screen. The researcher used a timer on the display screen, that was automatically reset at the start of each trial. The second screen displayed two words (the stimuli), presented on the left and right sides of the screen for 4000ms (font: Tahoma normal; size: 30). One of the words was a 'threat word' and the other a 'neutral (control) word'. Participants were instructed to read both words and keep reading them until they disappeared. The third screen, a blank screen, was automatically displayed for 1000ms. Prior to each trial, a drift check was performed. If the calibration error was more than 1° of visual angle, then a calibration was performed.

To avoid participant fatigue, trials were arranged into three equal blocks of 16 trials. After each block participants were given a self-timed break of 30 seconds or longer. The threat words in each block of trials came from one of three threat categories (1) 'sensory pain', (2) 'affective pain' or (3) 'general threat'. Each block only contained words from one

threat category. The eight words from each threat category (target) were paired with a 'neutral (control) word' matched for length and frequency in everyday language, using an English control word search engine (Table 1) (Guasch, Boada, Ferre, & Sanchez-Casas, 2013). Word pairs were presented twice within each block, with each word presented on the left and the right. The word pairs were randomised within each block, and the same word pair was not presented during consecutive trials. The order of blocks were randomised.

Threat Word Selection

The 'sensory pain' words (Table 1) were selected from a study that investigated the words that participants used to describe their back pain (Jensen, Johnson, Gertz, Galer, & Gammaitoni, 2013). The 'affective pain' words (Table 1) were selected from a study that investigated attentional bias in participants with acute low back pain (Sharpe et al., 2014). The general threat words (Table 1) have previously been used to investigate attentional bias to threat in chronic pain patients (Dehghani, Sharpe, & Nicholas, 2003).

Statistical Analysis

Outcome Measures

Twelve eye tracking outcome measures commonly used to assess attentional bias were calculated from the extracted data (Table 2) (Kimble, Fleming, Bandy, Kim, & Zambetti, 2010; Liossi et al., 2014; Yang et al., 2013). These outcome measures, selected *a priori*, were

chosen to reflect the different stages of attentional bias: overall attention, early

attention and late attention. Each outcome measure was calculated as a ratio of

fixation time of the target word to the control word, and then converted to a percentage. A

mean attentional bias score was calculated for each participant in each word category for

the test and retest sessions.

Data Reduction

Raw gaze data were automatically parsed into sequences of saccades and fixations

and loaded into SR research Eye Link® Dataviewer (V2.3.22; Ontario, Canada). The standard

cognitive configuration was used to define fixations (i.e. recording parse type: gaze saccade,

velocity threshold: 30ms, saccade acceleration threshold: 8000ms/s, saccade motion

threshold: $0.1ms/s^2$). A 100-pixel interest area, dependent on word length, was set around

each word, (i.e. the interest area was set relative to the start and end of each word). No

other filters were applied to the data, for example, no merge of fixations, no minimum

fixation duration, and no blink correction. An interest period was created for each

respective outcome measure and an interest area report was extracted. Subsequent data

filtering and reliability analysis was completed in STATA (v13.1; StataCorp, Texas, USA).

We excluded trials during which the eye tracker lost view of the eye and did not

regain view of the eye (e.g. trials in which a blink occurred were still included if the eye

tracker regained view of the eye after the blink), or when the participant did not adhere to

the instructions (i.e. participants were instructed to look directly at the middle of the

fixation cross until it disappeared and then read both words and keep reading them until they disappeared). Three criteria were used to exclude invalid trials:

1.   A fixation was not made to both interest areas. No detection of a fixation to both interest areas implies the eye tracker may have lost view of the eye and not regained the view of the eye, or the participant did not read both words (Mogg et al., 2003). As participants were instructed to read both words if a fixation was not captured on both words this was considered an invalid trial.

2.   The first fixation latency to either interest area was less than 30ms. Any fixations that occurred less than 30ms after word presentation were likely not due to the content of the words.

3.   Less than 3000ms (75%) of fixations were captured during the interest period (e.g. 0-4000ms) anywhere on the screen. That is, trials were still included trials if more than 75% of fixations were captured at any location of the screen not just within the interest areas. If less than 75% of fixations were captured during the interest period, the eye tracker may have lost tracking of the eye and not regained view of the eye, or the participant may have looked away from the screen after viewing both words (Fashler & Katz, 2014).

Participants were instructed to keep reading the words whilst they were presented. After applying these criteria, if more than 25% of a participant's trials were excluded then all of the participant's data were also excluded (Vervoort, Trost, Prkachin, & Mueller, 2013).

Reliability analysis

An intraclass correlation coefficient (ICC) was calculated to assess test retest reliability. ICCs are able to detect systematic differences between testing sessions and are preferred over other correlation coefficients such as Pearson's *r*, which in contrast does not consider systematic differences between testing sessions (Weir, 2005).

We used a two-way random effects model, with absolute agreement (ICC 2,1) (Shrout & Fleiss, 1979) as our primary outcome measure of test-retest reliability. A random effects model is preferred as it considers systematic differences between testing sessions. The single measure was used as this reflects how eye tracking is normally used in experimental research, i.e. participants are normally tested on one occasion. A two-way random effects model using an average measure (ICC 2,2) was also calculated. This average measure was included to indicate if testing people twice, and using the mean score, is more reliable than using the results from one testing session (supplementary material, Table 1). As per our protocol, we also calculated a two-way fixed effects model, with consistency of agreement (ICC 3,1) to investigate the consistency of the scores (supplementary material, Table 1) (Streiner, 2003b). A two-way fixed effects model does not consider systematic difference between testing sessions (de Vet et al., 2006a).

The standard error of measurement (SEM) was calculated as an indicator of measurement error. We deviated from our protocol (Open Science Framework, MT3K8), by using the variance scores, $SEM_{agreement} = \sqrt{\sigma^2_{retest} + \sigma^2_{residual}}$ (de Vet, Terwee, Knol, & Bouter, 2006b) instead of the standard deviation, $SEM = SD \times \left(\sqrt{1 - ICC_{2,1}}\right)$, to calculate the SEM. We did this because variance scores consider systematic differences between measurements (de Vet et al., 2006b). With each outcome measure entered as the dependent variable, the participants and the test retest sessions were considered random

factors in a mixed model to estimate the variance for the participants ($\sigma^2{}_p$), the test-retest variance ($\sigma^2{}_{retest}$) and the residual variance ($\sigma^2{}_{residual}$). These variances are reported in the supplementary material (Table 2).

Internal consistency, reflecting 'the interrelatedness of items on a test', was calculated using Cronbach's alpha for each set of words, for each outcome measure using scores from the first testing session (Cronbach, 1951; Streiner, 2003c).

Sample Size

We followed the recommendations from de Vet, Terwee, Mokkink, and Knol (2011) to calculate the required sample size. Using the simulated power calculations in Giraudeau and Mary (2001), we estimated that 50 participants would be required using two repeated measurements, to detect an ICC of .8, with a confidence interval of ±0.1 and alpha .05.

Results
Participants

We recruited and screened 50 participants from the community. Informed consent was obtained from all individual participants included in the study. After the preplanned data filtering 49 participants were included in the final analysis (see below). Mean participant age was 27.5 years (SD 10.0, range 18-73), 26 (52%) participants were female. Education details, psychological scales and language information are provided in Table 3.

Mean scores for depression, anxiety, stress and catastrophising were in the normal

range (Lovibond & Lovibond, 1995; Sullivan et al., 1995).

Data Reduction

We excluded 315 (6.56%) of trials in accordance with our pre-planned data filtering

procedure. 79 trials were excluded because no fixation was detected in both interest areas

(13 trials had no fixations to either interest area, 66 trials had a fixation in only one interest

area). 37 trials were excluded when a fixation was detected less than 30ms after the words

were displayed. 135 trials were excluded when less than 75% (3000ms) of fixations were

detected anywhere on the screen. The data reduction process resulted in one participant

with less than 75% of their trials remaining (i.e. <36 trials). For this participant, in addition to

the previously removed trials, all of the remaining trials were excluded (64 trials across both

testing sessions). 49 participants (4485 trials) were included in the final analysis.

Test-retest reliability

Test-retest reliability data are presented in Table 4. Point estimates ranged from ICC

(2,1): -.31 to .71. The sensory words had a lower mean ICC (.08) than the affective words

(.32), and the general threat words (.29). Considering only the affective words and general

threat words the *total dwell time (0-4000ms)* demonstrated the highest reliability (affective

words: ICC = .61, general threat words: ICC = .71). Reliability coefficients for the affective

and general threat words were also higher for the *total dwell time (500-4000ms)*, and *total dwell time (1000-4000ms)* (Table 4).

Measurement Error

The SEM results are presented in Table 4; lower SEMs represent a more stable outcome measure. Point estimates for the SEM ranged between 3.02% and 14.59% across all word groups in all outcome measures. All word groups demonstrated a similar pattern of SEM. The mean SEM was 5.59% for the sensory words, 4.82% for the affective words, and 4.98% for the general threat words. The *first fixation duration* recorded the lowest SEM scores (affective words SEM = 3.03%, general threat words SEM = 3.11%, sensory words SEM = 3.40%). The *second run dwell time* demonstrated the highest SEM, indicating less stable scores between testing sessions (affective words SEM = 13.43%, general threat words SEM = 11.21%, sensory words SEM = 14.49%).

Internal Consistency

Cronbach's alpha scores for the first testing session are presented in Table 4. Point estimates ranged from .57 to .99 (mean = .89). Most outcome measures reported high internal consistency, (e.g. *total dwell time*; affective words: α = .94, general threat words: α = .93, sensory words: α = .94). The lowest Cronbach's alpha scores were recorded for the *first fixation duration* (affective words: α = .57, general threat words: α = .67, sensory words: α = .70) and *second run dwell time* (affective words: α = .72, general threat words: α = .70, sensory words: α = .72).

Discussion

We assessed the reliability of a preferential looking eye tracking task to investigate attentional bias to threat related words in healthy participants. Test-retest reliability varied according to the threat word category (sensory pain words, general threat words, affective pain words) and outcome measure. Low ICCs were found for most outcome measures (e.g. first fixation latency), indicating they may not be appropriate for discriminative testing (when comparing between participant groups). The results for the measurement error (SEM) suggest stable outcome measure between sessions and for internal consistency (Cronbach's alpha) a high level of interrelatedness between word stimuli with each threat word category.

Test-retest reliability

Test-retest reliability varied according to the threat word category. Sensory pain words demonstrated the lowest test-retest reliability. Test-retest reliability considers the variance between a subject's repeated measurements relative to the overall group variance (de Vet et al., 2006b). Decreased participant variance, relative to measurement error, decreases test-retest reliability. When we examined the variance between participants ($\sigma^2{}_p$) across all word groups there was less variance between participants for the sensory pain words (Figure 1). It is not clear as to why the sensory pain words had less variance compared to the affective pain words and general threat words.

The *second run dwell time* demonstrated high participant variance (Figure 1), but still recorded low ICCs. The high variance between participants was not enough to overcome the relatively high measurement error between testing sessions.

Considering the different outcome measures available for researchers, our study showed that more reliable results are likely when using outcome measures that utilise more of the trial duration. Outcome measures that incorporated more of the 4000ms trial duration, such as *total dwell time of threat words (0-4000ms),* demonstrated higher test-retest reliability than outcome measures that used less of the trial duration, such as *total dwell time of threat words (0-500ms)*.

Furthermore, outcome measures selected to reflect early attention *(probability of first fixation to target word, first fixation latency, first run dwell time, first fixation duration)* had lower test- retest reliability than those selected to measure late attention *(second run dwell time, last run dwell time, total dwell time (500-4000ms), total dwell time (1000-4000ms)*. Early attention outcome measures used less of the available viewing time and demonstrated less variance between participants than late attention outcome measures (Figure 1). This demonstrates that both the threat word group selected and the proportion of viewing time incorporated in the outcome measure are important procedural variables for the test-retest reliability of eye tracking measures.

We found higher test- retest reliability than Price et al. (2015). In their study, using a paediatric sample, facial stimuli were presented for 2000ms, whereas in our study stimuli were presented for 4000ms (Price et al., 2015). It may be that increased stimulus exposure time allows greater variation, thereby increasing the ICC value. In support of this Lazarov et

al. (2016) presented stimuli for 6000ms and reported test-retest reliability of more than .62, using outcome measures that made use of longer stimulus exposure time e.g. total dwell time on threat faces. However, it may be that improved reliability for longer stimuli durations has a celling. The optimal stimuli duration, to optimise test-retest reliability, is likely related to the number and type of stimuli presented, e.g. more stimuli may require longer exposure times and pictures may require a longer presentation time than words. As noted by Waechter et al. (2014), reliability is task and population specific.

Measurement Error

The consistent and relatively low SEM values indicated stable measurements between sessions. The *second run dwell time* was an exception, demonstrating higher SEM values (affective words = 13.4%, general threat words = 11.2%, sensory words = 14.6%) than the other outcome measures (all less than 6.6%). This was explained by the test-retest variance and reflected in the standard deviations of the mean score (Table 4). The large standard deviations of the *second run dwell time* suggest there was considerable variability in the viewing pattern between test sessions. As the SEM *second run dwell time* values were higher than all other outcome measures we would caution using this outcome measure for discriminative or evaluative purposes, when other more reliable outcome measures are available. The results suggest the remaining outcome measures are appropriate for evaluative testing.

We are not aware of any other studies that have reported measurement error for eye tracking tasks that investigate attentional bias. We would encourage future research to

report measurement error alongside other indicators of reliability. As interest in using outcomes from eye tracking in interventional studies grows (Todd, Sharpe, & Colagiuri, 2016; Vazquez, Blanco, Sanchez, & McNally, 2016), it is important to know whether participant change scores are greater than the measurement error of the task.

Internal Consistency

Our internal consistency results suggest that fewer test items could be used to achieve the same scores. Internal consistency measures the interrelatedness among items, and as such, high Cronbach's alpha scores suggests that using fewer stimuli may achieve the same scores for participants. Waechter et al. (2014) reported similar internal consistency results in a preferential looking eye tracking task, measuring attentional bias using 72 trials. They reported Cronbach's alpha scores of .94, .94 and .96 for the total viewing time over 5000ms for angry, disgust and happy images, respectively. This further suggests that when using the more stable and reliable outcome measures (longer proportion of viewing time) fewer items could potentially be used, thus reducing time involved for testing (Scholtes et al., 2011).

Individual Variation

Researchers are commonly interested in testing for differences between groups. Test-retest reliability is the most informative reliability construct for that purpose. The nuance of test-retest reliability is that too little variance between participants will result in low reliability, (unable to distinguish participants). However, if measurements are not stable

between sessions, this will also produce low reliability (too much variability between measurements). These effects are highlighted when examining measures of early attention. Location of first fixation and first run dwell time both have low test-retest reliability, however this is likely due to different reasons.

Poor reliability for location of first fixation is most likely due to low variance between participants. Waechter et al. (2014) suggested low reliability may be due to the "look up" bias, where participants will consistently look up first if stimuli are presented vertically or look left first if stimuli are presented horizontally. Viewing the word on the left first is consistent with the normal left to right reading pattern observed in English readers (Liversedge & Findlay, 2000; Rayner, 1989). Decreased variability between participants, due to normal reading patterns, is likely to reduce the test-retest reliability for the location of first fixation. The low reliability coefficients reported for first fixation duration to threat words is likely due to poor stability of measurements between sessions. In this context other factors which influence viewing patterns such as global speed of processing may be at play. This hypothesis also extends to first run dwell time and 2nd run dwell time outcome measures. Individual viewing patterns influence the between participant variation.

It may be that outcome measures that use more of the available viewing time strike a balance in having sufficient between participant variance but similar enough scores between testing sessions. In this study outcome measures that used more of the stimulus duration (e.g. 0-4000ms) were stable between measurements, and also not confounded by other individual viewing patterns such as global speed of processing.

It must be emphasised that reliability is specific to the population and the task in which it has been evaluated. The results of our study using healthy participants, words as stimuli, and a presentation time of 4000ms cannot be assumed to generalise to other populations (e.g. anxiety patients), other stimuli (e.g. images), or presentation times (e.g. 500ms).

What is an acceptable level of reliability?

There is no definitive benchmark regarding an acceptable level of reliability (Charter & Feldt, 2001). Sample size, setting (i.e. clinical or research) and purpose (e.g. clinical diagnosis of life threatening illness) all contribute to the subjective assessment of what is acceptable in a specific situation. Whilst reliability benchmarks have not been well justified some guidance is necessary (Streiner, 2003b). Nunnally (1994) suggests a value of .70 may equate to modest reliability when used to compare groups, whilst Cicchetti (1994) suggested a tiered approach for determining acceptability (i.e < .40 = poor, .40 - .59 = fair, .60 - .74 = good, .75- 1.00 = excellent). We would caution against using eye tracking measures with reliability coefficients of less than 0.60 for research purposes. Outcome measures with higher reliability may be required when investigating between group differences with a small sample size (e.g. less than 20 participants). Our results suggest most outcome measures are not reliable enough to differentiate participants when assessing attentional bias in healthy participants using threat words. Some of the outcome measures, such as *the total dwell time of threat words (0-4000ms),* may be appropriate depending on the stimulus (i.e. general threat words are appropriate but not sensory words).

Limitations

Whilst it is important that reliability is established for a healthy sample, our results may not generalise to non-healthy samples. Reliability estimates are only valid for the sample being tested, and to the stimuli and outcome measures used in an experiment. The reliability of attentional bias using eye tracking has been investigated in a sample of participant with high and low social anxiety (Lazarov et al., 2016; Waechter et al., 2014). However, as these studies used facial images in non-clinical populations (participants were university students screened as having high or low social anxiety) it is unknown if these results generalise to other clinical samples. Further studies are required that investigate reliability in clinical samples using a variety of stimuli (words/ pictures/ faces), and outcome measures, across all three measurement properties of reliability (internal consistency, agreement, test-retest reliability).

Researcher degrees of freedom (RDoF) denotes the decisions researchers make when collecting and analysing data (Simmons, Nelson, & Simonsohn, 2011). There are many RDoF during eye tracking data filtering, e.g. what constitutes a valid trial, which fixations to retain for analysis. Minimising RDoF, by specifying in advance how data will be collected and analysed, decreases the risk of false positive results and may increase the reproducibility of findings (Simmons et al., 2011). We used a pre-planned data filtering process (Open Science Framework, MT3K8). Stating in advance how and why we planned to remove trials avoids biased and subjective influences on fixation locations (i.e. individual trials were not manipulated by the investigator). There is however, the potential for removing trials unnecessarily, and thereby decreasing the power of statistical analysis. We argue that

Potentially removing unnecessary trials is an appropriate compromise for increased transparency in data analysis, decreasing RDoF, minimising false positive results and potentially increasing reproducibility.

Our data filtering method excluded trials with a first fixation latency less than 30ms resulting in the exclusion of 46 trials. Previous research has used a more conservative cut off (e.g. 80-100ms), if we used a more traditional 80ms cut off, we would have included an additional 9 trials. Rather than include the additional 9 trials, we chose to preserve our a priori published data reduction plan. The first fixation latency cut off is another RDoF, and highlights the many decisions researchers must make.

Recommendations

Our results suggest that for discriminative testing, outcome measures with a short exposure time, or that use sensory words, may be unreliable (low test-retest reliability). However, for evaluative testing all of the outcome measures, except *second run dwell time,* may be appropriate (low measurement error). Given that we found high internal consistency yet low test-retest reliability, Cronbach's alpha should not be used to justify the reliability of a task (Gliner, Morgan, & Harmon, 2001; Streiner, 2003a).

Our findings suggest that outcome measures that investigate early stages of attentional bias are unreliable. One of the proposed advantages of eye tracking is the ability to distinguish early and late stages of attention. Our results suggest that the current outcome measures used to assess early stages of attention do not have adequate test-retest reliability and are therefore unable to distinguish reliably the different stages of attentional bias.

Comparing our results to other studies suggests that the test-retest reliability of eye tracking is superior to that of the dot probe task in healthy participants. Dear, Sharpe, Nicholas, and Refshauge (2011) reported bivariate reliability coefficients of -.06, -.14 and .01 for the dot probe task using words on two occasions in healthy participants. Schmukle (2005) reported similarly poor test-retest reliability coefficients using a word-based dot probe task. Evidence therefore suggests that when investigating attentional bias, eye tracking may provide higher test-retest reliability than the dot probe task. This however needs confirmation across different populations and with different stimuli. Any potential benefit gained from eye tracking, such as increased reliability, needs to be considered against the increased cost of eye tracking equipment and the more complex data analysis techniques.

The challenge moving forwards is to use outcome measures and stimuli that are both relevant to the population and the underlying mechanism being investigated, whilst still providing reliable data. We suggest the reporting of reliability statistics; test-retest, measurement error and internal consistency, for all tasks and outcome measures used to investigate attentional bias. With the rapid advances in technology and the emerging prospect of virtual reality to assess attentional bias it is critical that reliability is reported.

Conclusion

The outcome measure and threat word category used in eye tracking experiments influence test- retest reliability. Outcome measures with longer exposure times have

increased test- retest reliability. Measurement error in eye tracking appears to be low.

These results require replication in clinical populations and with different stimuli.

Compliance with Ethical Standards

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Conflict of Interest: GLM has: received support from Pfizer, Australian Institute of Sport, Grunenthal, Kaiser Permanente California, Return to Work SA, Agile Physiotherapy, Results Physiotherapy); Grants from National Health and Medical Research Council of Australia; Speaker fees for lectures on pain and rehabilitation; Royalties from Explain Pain, Painful Yarns, Graded Motor Imagery Handbook, The Explain Pain Handbook: Protectometer, Noigroup Publications. All other authors declare they have no conflict of interest.

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Table 1 Threat (target) and matched neutral (control) words presented to participants

Sensory Pain		Affective Pain		General threat	
Target	*Control*	*Target*	*Control*	*Target*	*Control*
sharp	minor	tiring	orient	crushing	footpath
ache	eats	unbearable	delicately	frightful	stonework
throbbing	visionary	punishing	polishing	terrifying	theatrical
cramping	allusive	exhausting	decisively	threat	sounds
burning	samples	annoying	marketed	scared	drives
dull	maps	troublesome	nutritional	danger	fields
shooting	entering	irritating	installing	harmful	drifted
pain	hill	nagging	planner	suffocating	interviewee

Table 2 Outcome measures and associated equations used to assess the different stages of attentional bias

Stage of Attention	Outcome Measure and Equation
Overall attention	Total dwell time of threat words (0- 4000ms): $$\frac{\text{mean dwell time of target word 0-4000ms}}{(\text{mean dwell time of target word 0-4000ms} + \text{mean dwell time of control word 0-4000ms})}$$ Total dwell time of threat words (0- 500ms): $$\frac{\text{mean dwell time of target word 0-500ms}}{(\text{mean dwell time of target word 0-500ms} + \text{mean dwell time of control word 0-500ms})}$$ Total dwell time of threat words (0- 2000ms): $$\frac{\text{mean dwell time of target word 0-2000ms}}{(\text{mean dwell time of target word 0-2000ms} + \text{mean dwell time of control word 0-2000ms})}$$ Total dwell time of threat words (0- 3000ms): $$\frac{\text{mean dwell time of target word 0-3000ms}}{(\text{mean dwell time of target word 0-3000ms} + \text{mean dwell time of control word 0-3000ms})}$$
Early Attention	Probability of first fixation to target word: $$\frac{\text{number of times the first fixation was to the target word}}{\text{total number of trials with a first fixation}} \times 100$$ Latency to first fixation of threat words: $$\frac{\text{mean latency of first fixation to target word}}{(\text{mean latency of first fixation to target words} + \text{mean latency of first fixation to control word})}$$ First run dwell time of threat words: $$\frac{\text{mean first run dwell time target word}}{(\text{mean first run dwell time target word} + \text{mean first run dwell time control word})}$$ First fixation duration of threat words: $$\frac{\text{mean first fixation duration}}{\text{mean first fixation duration target word} + \text{mean first fixation duration control word}}$$
Late Attention	Second run dwell time of threat words: $$\frac{\text{mean second run dwell time target word}}{(\text{mean second run dwell time target word} + \text{mean second run dwell time control word})}$$ Last run dwell time of threat words: $$\frac{\text{mean last run dwell time target word}}{(\text{mean last run dwell time target word} + \text{mean last run dwell time control word})}$$ Total dwell time of threat words (500- 4000ms):

$$\frac{\text{mean dwell time of target word 500-4000ms}}{\text{(mean dwell time of target word 500-4000ms + mean dwell time of control word 500-4000ms)}}$$

Total dwell time of threat words (1000- 4000ms):

$$\frac{\text{mean dwell time of target word 1000-4000ms}}{\text{(mean dwell time of target word 1000-4000ms + mean dwell time of control word 1000-4000ms)}}$$

Table 3 Education, psychological scales and language data for participants included in the final analysis

Participant Characteristics	N	Score	SD	Range
Highest level of education				
High School	16 (33%)			
Diploma TAFE	3 (6%)			
Bachelor Degree or higher	30 (61%)			
Psychological Scales				
DASS-21: Depression (0-21)		1.2	1.8	0-6
DASS-21: Anxiety (0-21		1.2	1.7	0-7
DASS-21: Stress (0-21)		2.6	2.4	0-9
Pain Catastrophising Scale (0-52)		9.7	10.4	0-33
Self-rated proficiency in English (LEAP-Q)				
Speaking (0-10)		8.7	1.1	7-10
Understanding (0-10)		8.9	1.0	7-10
Reading (0-10)		9.0	1.0	7-10

DASS-21 Depression Anxiety and Stress Scales
LEAP-Q Language Experience and Proficiency Questionnaire

Table 4 Mean results from the two testing sessions, internal consistency as measured with Cronbach's alpha, test retest reliability as measured with ICC (2,1), and measurement error as measured with the Standard error of measurement (SEM).

Stage of attention	Outcome Measure	Word Category	Mean Test 1	SD Test 1	Mean Test 2	SD Test 2	Cronbach's α	ICC (2,1)	95%CI		SEM
Overall Attention	Total Dwell Time (0-4000ms)	Affective	48.86%	5.62%	48.81%	5.03%	0.94	0.61	0.39	0.76	3.34%
		General Threat	48.06%	5.96%	48.76%	7.48%	0.93	0.71	0.55	0.83	3.61%
		Sensory	49.42%	3.47%	48.55%	6.18%	0.94	0.20	-0.08	0.46	4.47%
Overall Attention	Total Dwell Time (0-500ms)	Affective	48.89%	4.62%	50.60%	5.18%	0.99	-0.01	-0.28	0.26	5.00%
		General Threat	50.23%	4.26%	49.41%	5.24%	0.98	-0.31	-0.54	-0.02	4.76%
		Sensory	50.70%	4.13%	49.98%	5.34%	0.99	0.12	-0.16	0.39	4.46%
Overall Attention	Total Dwell Time (0-2000ms)	Affective	48.76%	4.12%	50.02%	3.68%	0.85	0.43	0.17	0.63	3.02%
		General Threat	46.85%	4.75%	48.18%	5.68%	0.88	0.44	0.19	0.64	3.95%
		Sensory	49.15%	3.92%	48.85%	4.65%	0.90	0.21	-0.08	0.47	3.79%
Overall Attention	Total Dwell Time (0-3000ms)	Affective	49.11%	4.66%	49.25z`%	4.25%	0.91	0.51	0.27	0.69	3.11%
		General Threat	47.86%	5.66%	48.72%	6.21%	0.92	0.62	0.42	0.77	3.65%
		Sensory	49.50%	3.76%	48.89%	5.35%	0.95	0.17	-0.11	0.43	4.18%
Early Attention	Probability of First Fixation to target word	Affective	50.83%	6.22%	49.93%	6.12%	0.97	-0.15	-0.42	0.14	6.16%
		General Threat	49.09%	4.80%	50.48%	6.35%	0.96	-0.18	-0.43	0.11	5.65%
		Sensory	49.07%	6.84%	49.58%	6.22%	0.96	0.06	-0.23	0.33	6.30%
Early Attention	First Fixation Latency	Affective	50.61%	2.94%	49.89%	3.50%	0.98	0.13	-0.15	0.39	3.03%
		General Threat	49.97%	2.59%	50.46%	3.57%	0.98	-0.30	-0.54	-0.02	3.11%
		Sensory	49.75%	3.28%	49.98%	3.66%	0.98	0.03	-0.26	0.31	3.40%
Early Attention	First Run Dwell Time	Affective	49.21%	4.22%	50.02%	3.32%	0.93	0.32	0.05	0.54	3.16%
		General Threat	47.87%	4.24%	49.17%	4.63%	0.91	0.22	-0.06	0.46	3.98%
		Sensory	49.48%	4.38%	49.53%	3.77%	0.94	0.10	-0.19	0.37	3.84%
Early Attention	First fixation Duration	Affective	50.26%	4.90%	48.68%	5.40%	0.57	0.30	0.03	0.53	4.40%
		General Threat	49.21%	5.46%	49.53%	5.19%	0.67	0.01	-0.28	0.29	5.25%
		Sensory	48.95%	5.14%	48.37%	4.81%	0.70	-0.15	-0.42	0.14	4.96%
Late Attention	Second Run Dwell Time	Affective	49.84%	13.64%	46.24%	15.70%	0.72	0.16	-0.12	0.42	13.43%
		General Threat	52.40%	14.96%	49.79%	16.52%	0.70	0.50	0.25	0.69	11.21%
		Sensory	50.22%	11.45%	44.67%	16.49%	0.72	-0.02	-0.28	0.25	14.59%
Late Attention	Last Run Dwell Time	Affective	50.80%	6.06%	48.64%	5.86%	0.82	0.49	0.25	0.68	4.36%
		General Threat	47.95%	6.42%	47.88%	8.44%	0.84	0.36	0.08	0.58	5.98%
		Sensory	49.95%	4.99%	48.73%	7.79%	0.83	-0.17	-0.43	0.12	6.54%
Late Attention	Total Dwell time (500-4000ms)	Affective	48.78%	6.17%	48.67%	5.72%	0.96	0.57	0.34	0.73	3.89%
		General Threat	47.77%	6.61%	48.77%	7.97%	0.95	0.70	0.52	0.82	4.03%
		Sensory	49.35%	4.02%	48.45%	6.71%	0.96	0.24	-0.05	0.48	4.83%
Late Attention	Total Dwell time (1000-4000ms)	Affective	48.90%	7.68%	48.63%	6.90%	0.96	0.54	0.31	0.72	4.91%
		General Threat	48.07%	7.36%	49.04%	9.10%	0.96	0.70	0.52	0.82	4.56%

Sensory	49.57%	4.31%	48.53%	8.01%	0.96	0.21	-0.08	0.46	5.72%

Figures
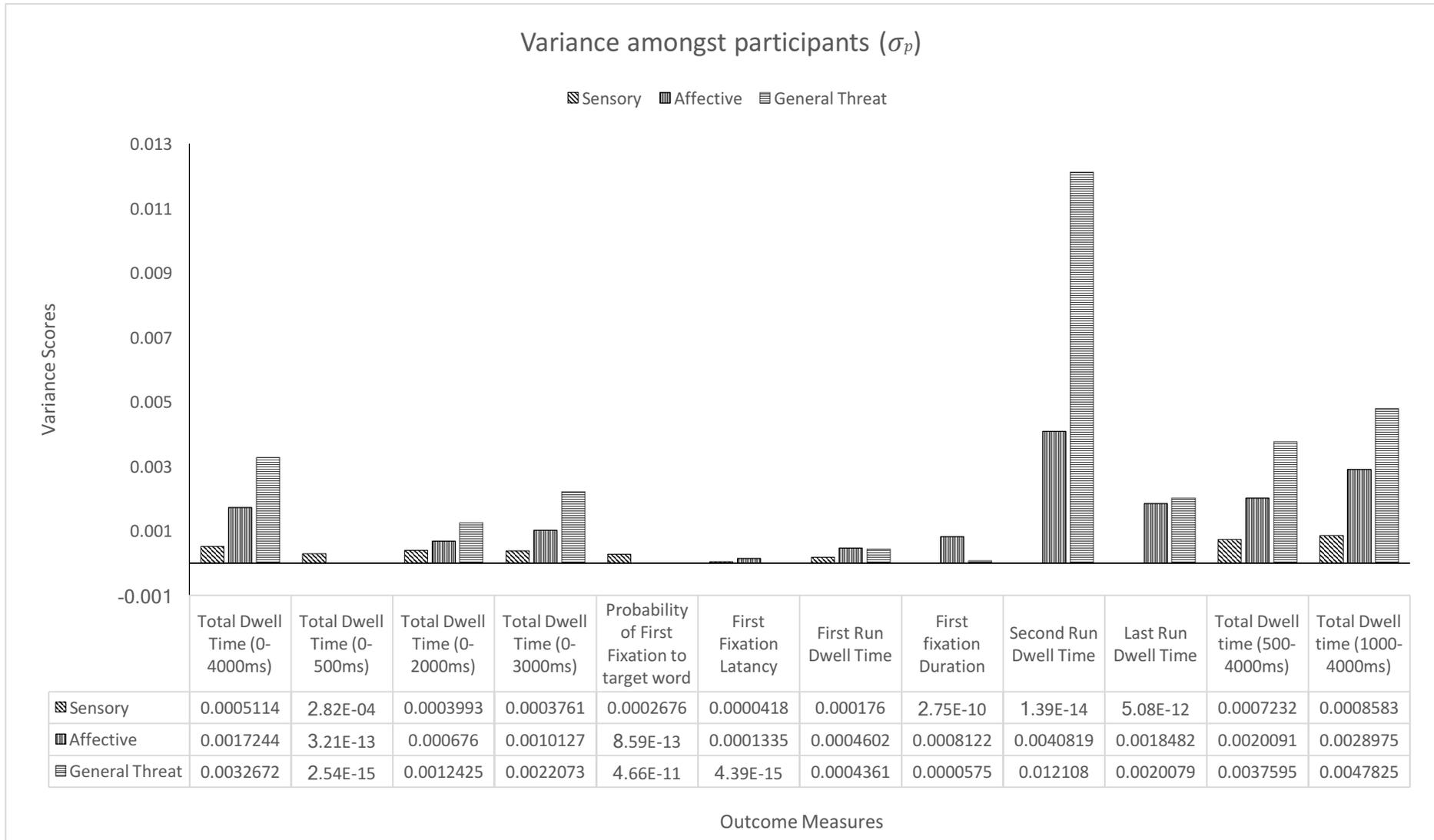
Figure 1 Participant variance ($\sigma^2{}_p$) for each outcome measure