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Inspection time and visual–perceptual processing

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Abstract

Inspection time (IT) is the most popular simple psychometric measure that is used to account for a large part of the variance in human mental ability, with the estimated corrected correlation between IT and IQ being −0.50. In this study, we investigate the relationship between IT and the performance and oculomotor variables measured during three simple visual tasks. Participants' ITs were first measured using a slight variation of the standard IT task, which was followed by the three simple visual tasks that were designed to test participants' visual–attentional control and visual working memory under varying degrees of difficulty; they included a visual search task, a comparative visual search task, and a visual memorization task. Significant correlations were found between IT and performance variables for each of the visual tasks. The implications of the correlation between IT and performance-related variables are discussed. Oculomotor variables on the other hand only correlated significantly with IT during the retrieval phase of the visual memorization task, which is likely a product of differences in participants' ability to memorize objects during the loading phase of the experiment. This leads us to the conclusion that the oculomotor variables we measured do not correlate with IT in general, but may in the case where a systematic benefit would be realized.

Keywords: Elementary cognitive task; Inspection time; Eye movements; Visual search; Comparative visual search; Visual working memory; Visual processing

1. Introduction

The search for the psychological bases of human intelligence has led psychologists to attempt to find a simple psychometric intelligence test that can account for individual differences in mental ability. While there has been some success in finding significant correlations between the results from simple reaction time tests and IQ (Hick, 1952; Sternberg, 1966), these methods have been largely rejected due to their weak correlations and their weak basis for explaining their link to individual differences in mental ability (Brody, 1992; Detterman, 1987; Jensen, 1987). In their stead, another measure, inspection time (IT), has proven to account for a significant portion (approximately 25%) of the variance in human intelligence (Deary & Stough, 1996).

Originally, the notion of IT was derived from a model of simple, perceptual decision-making (Vickers, Nettelbeck, & Wilson, 1972), and was designed to be fundamental enough as to be "relatively immune from influence by higher cognitive activities or by motivational and social factors" (Vickers & Smith, 1986). In its most prevalent form, the IT task begins with participants being warned of an impending stimulus by a simple cue figure (see Fig. 1a). Immediately following the cue, participants are shown a figure with two parallel, vertical lines adjoined at their tops by a horizontal line, with one vertical line being longer than the other (see Fig. 1b); this figure is commonly referred to as the "pi-figure". Following the presentation of the pi-figure, a backward-mask is presented to disrupt any processing of an iconic image (Fig. 1c illustrates the backward-mask used for this experiment); typical presentation times for the stimulus range from <10 to >300 ms (varying greatly between implementation) and 200 to 1000 ms for the mask. Typically, the participant then

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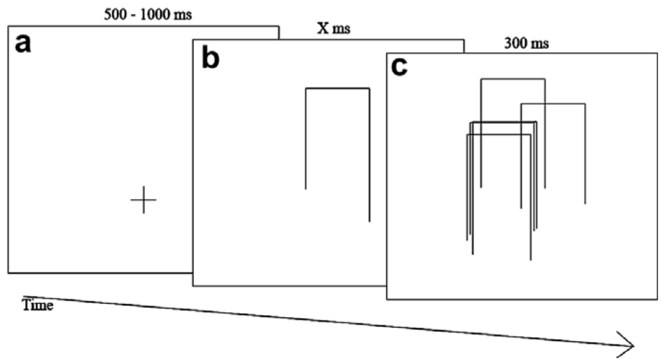

Fig. 1. IT task images: (a) the cue figure presented just prior to stimulus onset to focus attention. (b) IT stimulus, commonly referred to as the 'pi-figure'. (c) The backward-mask presented after stimulus presentation to prevent any iconic-image processing.

responds to which of the two vertical lines of the pi-figure they perceived to be longer (or shorter); there is no pressure to respond in a certain amount of time. The participant is shown this cue-stimulus-mask over a range of stimulus presentation times (i.e. time intervals that the pi-figure is visible), referred to as stimulus onset asynchronies (SOAs). Afterwards, a participant's inspection time is generally computed as the amount of time the stimulus must be presented for the participant to achieve some preset level of accuracy (e.g. 75% or 90%). It is important to note that IT is measured as the stimulus presentation time needed and not the response time, as participants are allowed as long as they like to respond to the sensory input.

IT is often described as a measure of the amount of time required by a participant to make a single observation of sensory input. This measure is theorized by many to capture an insight into basic cognitive abilities (Brand & Deary, 1982; Nettelbeck, 1987; Vickers et al., 1972). One theory places IT as a measure of general processing speed (Burns & Nettelbeck, 2003; Burns, Nettelbeck, & Cooper, 1999). Despite the large amount of work that has been performed to develop IT as a psychometric measure, there remain many unresolved issues regarding IT. For instance, the mask originally used by Vickers et al. (1972) has been shown to exhibit a mask-breaking effect that can be used to undermine the IT measurement (e.g. Alexander & Mackenzie, 1992; Egan, 1986, 1994; Egan & Deary, 1992; Evans & Nettelbeck, 1993; Knibb, 1992). This mask-breaking effect was often present in the form of apparent motion, which could be used by participants to artificially improve their IT. At present, there is also an open disagreement as to what IT is actually a measure of. Originally, IT was theorized as a measure of the speed of sensory processing, but White (1993, 1996) and Burns, Nettelbeck and White (1998) have disputed this and claimed that IT is in fact a measure of the speed of a post-sensory encoding mechanism. Perhaps the most pressing unresolved matter relating to IT is the causal direction between IT and IQ. In its nascent period, IT was accepted by many researchers to partly cause individual differences in human intelligence (Brand & Deary, 1982; Raz, Willerman, & Yama, 1987; Vickers & Smith, 1986), but Deary (2000, 2001) and Deary and Stough (1996) have stated the dangers in following this simple assumption. Given these open issues of IT, it is clear that IT is far from being fully understood as a psychometric measure.

Although there is much research that uses IT as a metric to compare or contrast two groups of participants (e.g. Badcock, Williams, Anderson, & Jablensky, 2004; Burns & Nettelbeck, 2005; Kelleher, Stough, Sergejew, & Rolfe, 2004), there is little research that relates IT to individual differences outside of intelligence. It is our intent to investigate the presence of individual, oculomotor differences between participants with low and high ITs. Oculomotor differences refer to observable differences in the mechanical measures of one's eye movements. For instance, when we observe a visual scene, read a passage, or attempt to locate an object in a visual scene, we employ very quick eye movements to shift the location of our visual field; these brief eye movements are referred to as saccades. Between these saccades our eyes remain relatively still while we collect information from the present visual field; these intervals are commonly referred to as fixations. Both saccades and fixations can be broken into simple oculomotor measures that have been shown to provide valuable insight into the underlying neural processes of a participant (Rayner, 1998). In particular, the temporal length of a fixation, referred to as fixation duration, and the physical distance traversed during a saccade, referred to as saccade length, have been shown to be influenced by processing difficulty (Pollatsek, Rayner, & Bolota, 1986). We further speculate that consistent differences in either or both of these two variables could exist between participants with low and high ITs. Given that IT is a measure of the speed of intake of information and that fixation duration may depend upon the completion of foveal analysis (Hooge & Erkelens, 1996, 1998), it is possible that participants with a low IT may exhibit significantly shorter fixation durations than participants with a high IT during the same task. Alternatively, fixation durations may be similar across participants with low and high ITs if lower-IT participants use their faster intake of information to acquire information from a larger visual area, which may result in significantly longer saccades instead. In addition to fixation duration and saccade length, initial saccade latency and relative pupil variance were also tracked. Initial saccade latency refers to the amount of time required to initiate the first saccade after the presentation of a stimulus, and has been shown to increase when a number of saccades are planned in sequence (Inhoff, 1986). Relative pupil variance is computed as the difference between a participant's minimum and maximum pupil size divided by their minimum pupil size, and has been previously shown to be an indicator of cognitive load (Kahneman, 1973; Kahneman & Beatty, 1966; Kahneman, Beatty, & Pollack, 1967); we will also be using this measure as an estimate of cognitive load; for a review of pupil size as a measure of cognitive load, see Beatty (1982).

In an attempt to investigate differences in these oculomotor measures, participants performed a series of visual tasks after first measuring their IT. ITs were measured using a slightly modified version of the standard IT task; specifically, we used an overload mask to reduce the use of any mask-breaking effect along with an algorithm that individualizes the IT testing session by testing participants using only individually relevant SOAs. After successfully measuring the participants' IT, they then participated in three visual tasks: a common feature/conjunctive visual search task; a comparative visual search task in which participants attempted to locate a discrepancy in two spatially separated sets of objects; and a visual memorization task in which participants attempted to locate a discrepancy in two temporally separated sets of objects. These three tasks were chosen because of their individual relationship to one, or both, of two important factors that determine visual behavior; these being visual–attentional control and visual working memory. In addition to tracking differences between low- and high-IT participants in oculomotor measures during the visual tasks, we also tracked differences in task-performance measures, which could offer insight into the true nature of IT as a psychometric test.

Visual searches are a large part of everyday life for most of us; in fact, we perform visual searches so often that most of the time we do not even realize that we are doing so; when we search for our keys, attempt to dodge vehicles while crossing the road, or scan for a piece of data in plain text, we are performing a visual search. Visual search tasks have consequently become a prominent paradigm used to gain insight into our visual attention system; see Wolfe (1998) for a review of visual search. In the visual search task presented here, we have participants attempt to locate a target object among distracter objects under three separate conditions of varying difficulty. This form of visual search task has been repeatedly used in eye movement studies because of its intrinsic relation to the control of visual attention. Conceptually, the IT task and the feature-search conditions of the visual search task used in the current study are quite similar in nature in that both require the efficient processing of simple visual information. Given this, it is likely that participants who performed well on the IT task (those with lower ITs) will show similar performance capabilities in the visual search task through their faster intake of sensory information.

As with visual search tasks, comparative visual search tasks rely on stringent visual–attentional control (Pomplun et al., 2001). However, unlike visual search tasks, comparative visual search tasks require the effective use of visual working memory for task completion. The comparative visual search task presented here has participants locate a single difference between two nearly identical sets of objects displayed on the left and right sides of the screen, referred to as hemifields. Since the hemifields were setup so that participants cannot simultaneously attend to both sets at the same time, participants must first "load" their visual working memory with objects from one hemifield and then "retrieve" what they have loaded to make a comparison against the objects in the opposite hemifield. As with the visual search task, the comparative visual search task is presented to participants under varying levels of difficulty. Given the nature of IT, it is possible, or even likely, that participants with a low IT can load their working memory faster than participants with a high IT, which would allow them to load more objects into memory during the same amount of time. Consequently, we predict that participants with a low IT will be significantly faster (i.e. exhibit shorter response times) at locating the difference between the two hemifields while exhibiting evidence of larger visual working memory loads than participants with a high IT.

Unlike visual search tasks and comparative visual search tasks, visual memorization task performance is not directly affected by visual–attentional control, assuming that the participant has sufficient control to functionally navigate the display. In the visual memorization task presented here, participants attempt to locate a single difference between two nearly identical sets of objects that are consecutively presented to the user. The visual memorization task and comparative visual search task are similar in that subjects must load and compare objects to locate a difference between two sets of objects; however, in the visual memorization task, the participant is afforded only one attempt to load the necessary information from the first set of objects. Furthermore, the number of objects presented in the first display greatly exceeds the theorized visual working memory capacity (Pashler, 1988; Vogel, Woodman, & Luck, 2001). Consequently, the visual memorization task also relies on a participant's ability to employ a memorization strategy, such as perceptual grouping, to load the objects into memory. As an extension of our previous hypothesis that lower-IT participants can load their visual working memory more quickly than higher-IT participants, we hypothesize that lower-IT participants will be able to complete the visual memorization task more accurately than high-IT participants for two reasons. One; since low-IT participants will presumably be able to fill their visual working memory quicker, they will have significantly more time to memorize the objects. Two; given the correlation between IT and IQ, lower-IT participants should be more capable of formulating and applying a memorization strategy.

2. Experiment 1: Inspection time task

To record participants' ITs, we devised an IT task modeled after the standard, backward-masked IT task with two slight changes. One, the mask used originally by Vickers et al. (1972) has been shown to exhibit a mask-breaking effect, and as such, we designed a mask similar in motivation to that used by Knibb to reduce this effect (1992); simply put, the mask attempts to "overload" the participant's visual field, thus preventing any processing of an iconic image. Two, the standard IT task requires participants to perform the same number of trials across a wide range of

SOAs regardless of their relevance to a particular participant. In an attempt to reduce the number of irrelevant trials (and therefore the overall length of the IT task), we have created an algorithm that actively pursues only the SOAs that are relevant to computing a participant's IT. Similar adaptive algorithms are used by other researchers (e.g. Burns & Nettelbeck, 2003).

2.1. Method

2.1.1. Participants

The IT task was performed with the assistance of 35 naïve participants that were paid a $10 honorarium for their participation. Of the 35 participants, 22 were male and 13 were female; 16 were undergraduate students, 17 were graduate students, and 2 were faculty at the University of Massachusetts Boston. The median age was 28 and ranged from ages 18 to 41. All of the participants had intact vision and some used corrective lenses.

2.1.2. Apparatus

Stimuli were presented on a 21-in. Dell P1130 monitor using the resolution 1024×768 and a refresh rate of 120 Hz. Participants sat approximately 60 cm from the screen resulting in a horizontal and vertical viewing angle of 31.5° and 24.6°, respectively. Participants' responses were recorded using a standard PC mouse.

2.1.3. Materials

The IT task target-stimulus, referred to as the 'pi-figure', consisted of two vertical, parallel lines connected to a horizontal line at the top of each vertical line (Fig. 1b). The pi-figure comes in two forms, one with the left, vertical line slightly longer and one with the right, vertical line slightly longer; Fig. 1b represents the latter. The line lengths for the target-stimulus are 3.4°, 5.1°, and 6.8° for the horizontal, short-vertical, and long-vertical lines, respectively. The added length to one of the vertical stimulus-lines was designed to subtend a visual angle such that, given adequate viewing time, a discriminative judgment is performed perfectly for those with normal or corrected-to-normal vision, and was 1.7° for our experiment. To focus participants' attention, a simple cue in the form of a cross was presented immediately prior to stimulus onset (Fig. 1a). Immediately following presentation of the stimulus, a mask was presented to disrupt any processing of an iconic image. The mask was composed of five pi-figures randomly placed in the immediate area of the previous stimulus (Fig. 1c).

2.1.4. Procedure

Prior to the start of the experiments, each participant was given instructions about their task. To accustom participants with the task, six initial practice trials were performed starting with extremely large SOAs and leading to moderately low SOAs. During the first practice trial, the IT stimulus was presented to the participant for 750 ms. The following five practice trials presented the target-stimulus for 750 ms, 750 ms, 525 ms, 300 ms, and 150 ms, respectively; the first experimental trial was then presented for 75 ms. Prior to every target-stimulus presentation, the cue figure was presented for a random period of time between 500 and 1000 ms. Immediately following the presentation of the stimulus, the backward-mask was presented for 300 ms.

As they were instructed, the participants pressed the left or right mouse button to indicate they believed the left or right vertical line was longer, respectively. Following a participant's response, the next cue-stimulus-mask triplet was presented. Participants were instructed to focus on the accuracy of their response and to take as long as they needed to make their response. The stimulus presentation period varied with the accuracy of a participant's responses in such a way that presentation times, which were consistent for two cycles of the cue-stimulus-mask triplet, were increased by 8.3 ms if the participant responded incorrectly to one or both trials or were decreased by 8.3 ms if the participant responded correctly to both. This process continued until two presentation periods could be identified; one in which the participant responded correctly $\geqslant 75\%$ of the trials, and one in which they responded correctly $\leqslant 75\%$ of the trials with at least 36 trials for each. The participant's IT was then operationally defined by using linear interpolation to estimate the time at which the participant responded correctly for exactly 75% of the trials.

2.1.5. Results

Inspection times were obtained for all but one participant, whose IT response-accuracy fluctuated too greatly due to not fully understanding the task; this participant was excluded from Experiments 2 through 4. Recorded ITs varied from 33.3 to 158.3 ms with a mean of 80.1 ms and a standard deviation of 23.4 ms. A Shapiro–Wilk test of normality was performed and demonstrated that the IT data represents a non-normal distribution ($df = 34$, Statistic $= 0.91$, $p < 0.01$). Consequently, correlations to IT will be performed using Spearman's non-parametric correlation rho, or ρ.

To analyze differences between participants with low and high ITs, a median split was performed such that two groups of 17 were formed from the 34 participants that participated in Experiments 2 through 4. The low-IT group had a mean of 63.5 ms and a standard deviation of 10.2 ms. The high-IT group had a mean of 96.6 ms and a standard deviation of 21.1 ms.

3. Experiment 2: Visual search task

In order to examine the differences between low- and high-IT participants in task-performance and oculomotor measures, participants performed a common visual search task. Specifically, participants searched a display for a black, horizontal bar among a set of white, vertical and white, horizontal distracters (color feature-search), or white, vertical and black, vertical distracters (orientation feature-search), or white, horizontal and black, vertical distracters (conjunctive-search). This particular visual search task was chosen because of its similarities to the IT task (both tasks depend heavily on the efficient processing of simple stimuli to complete the task) and its prominence in visual search literature. Classically, simple feature-search conditions were thought to be searched in parallel while conjunctive-search conditions were said to be serially searched, but presently, the consensus is rather that the two conditions represent two positions on a continuum of the number of searchable objects within a single fixation (Treisman & Gelade, 1980; Wolfe, 1998). Loosely speaking, in these feature-search conditions, the target object seems to "pop out" from the distracter objects. The target object in the conjunctive-search condition, on the other hand, is not as readily locatable as the one in the feature-search conditions. We consequently predict that participants will, on average, be significantly better at locating the target object in the feature-search conditions after a single fixation than in the conjunctive-search condition, which we will verify by measuring the distance from the gaze-position to the target after a single saccade has been made. Furthermore, if a lower-IT indeed affords participants a larger visual field that can be processed within a single fixation, it is possible that lower-IT participants will also show a greater ability to locate the target object during their first fixation.

3.1. Method

3.1.1. Participants and apparatus

The 34 participants that finished the IT task participated in the visual search task. Stimuli were presented on the same monitor that was used for the IT task using the same resolution and refresh rate. Participants were seated at the same distance from the monitor as in the IT task yielding the same viewing angles. Eye movements were recorded using the SR Research Eye-Link II eye-tracker system. The average error of visual angle in this system is 0.5°, and its sampling frequency is 500 Hz. During the visual search task, responses were recorded using a handset (often referred to as a game-pad).

3.1.2. Materials

Displays presented during the visual search task were composed of a combination of vertical and horizontal, black and white bars, which measured 2.1° in length and 0.7° in width. Each display contained 40 of these bars, and exactly one of these was a black, horizontal bar which was the target object. Displays were divided into three categories: color-search (Fig. 2a), orientation-search (Fig. 2b), and conjunctive-search (Fig. 2c). Objects in the color-search displays consisted of an equal mix of objects that differed from the target object in their color or in both their color and orientation. Orientation-search displays differed from the target object in their orientation or in both their orientation and color. Conjunctive-search displays were composed of objects that always differed from the target object in one dimension. Objects were randomly placed in a screen-centered display area which had a length and width of 20.7°; the minimum distance between object centers was 2.6°. All displays were generated prior to starting

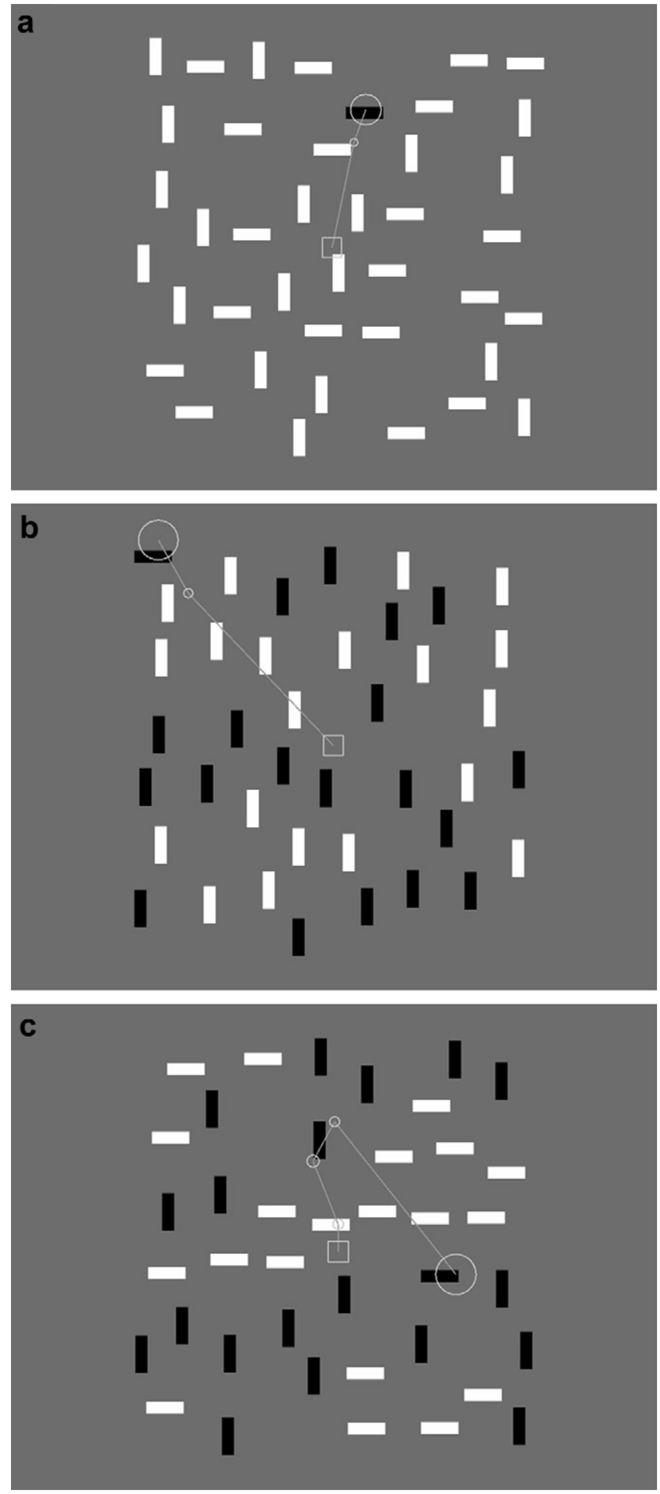

Fig. 2. Visual search task images with sample eye movements of a participant superimposed on each. (a) Example color-search display; (b) example orientation-search display; (c) example conjunctive-search display.

the experiment so that each participant was subject to the same set of displays.

3.1.3. Procedure

Participants were informed of the categories of the displays and of the identity of the target object prior to starting the experiment. They were instructed to find the target object in each trial as quickly and as accurately as possible, and to press a button on the game-pad while fixating on the target object. Prior to starting the experiment trials, participants were fitted with the eye-tracker headset, which was followed by the calibration of the eye-tracker system. Participants were then tested under three conditions: a color-search condition, an orientation-search condition, and a conjunctive-search condition; each condition was composed solely of displays from their respective display category. Trial conditions were presented in blocks of 10 trials plus two training trials that were presented the first time a trial condition was presented. Participants were shown eight blocks of trials that were broken down into two color-search blocks, two orientation-search blocks, and four conjunctive-search blocks. The ordering of blocks and displays within each block were completely randomized, except for the two training displays, which were always presented at the start of the blocks they were present in. Prior to each trial, a simple drift correction was performed in which participants were instructed to fixate on a dot shown in the center of the screen and press a button to start the trial. Trials ended only after the button press, indicating the participant was fixating on the target object.

3.1.4. Results

The distance between participants' fixation location at the button press and the target object, referred to as trial accuracy from here on, was 2.3° with a standard deviation of 0.6°, and no significant difference was found between participants in the low IT group (2.2°) and those in the high IT group (2.5°), $t(32) = 1.42$, $p > 0.1$. To provide a baseline to compare trial accuracies against, rotated trial accuracies were also computed by rotating the display 180° around its center and computing the distance between participants' non-rotated final-fixation location and the rotated target-object; rotated trial accuracy was 7.3° with a standard deviation of 2.2°. The significant difference between these two accuracy measures, $t(33) = 12.50$, $p < 0.001$, makes it clear that participants were in fact performing their task.

Excluding the trial accuracies, means, low-IT group means, and high-IT group means, as well as standard deviations, of variables measured during the three visual tasks are given in Tables 1–7. Non-parametric correlations with IT and internal reliabilities, computed using Spearman's rho and the Spearman–Brown prophecy formula, respectively, are also listed in Tables 1–7. The Spearman–Brown calculation involved a split-half calculation using even and odd trials. Trial durations during the conjunctive-search condition correlated significantly with IT, $\rho(32) = 0.43$, $p < 0.05$, but trial durations during the color-search and orientation-search conditions only showed a tendency to correlate with IT, $\rho(32) = 0.30$, $p = 0.08$, and $\rho(32) = 0.29$, $p = 0.09$, respectively. To examine the difference between conditions, a two-way ANOVA was computed for trial durations with IT group (low IT vs. high IT) as a between-subject factor and condition (conjunctive-search vs. color-search vs. orientation-search) as a within-subject factor. A significant main effect was found

Table 1
Performance-related variables measured during each condition (a, conjunctive-search condition; b, color-search condition; c, orientation-search condition) of the visual search task and their non-parametric correlations to IT (ρ), means and standard deviation for all participants (*M* (*SD*)), and the means and standard deviations for participants in the low- and high-IT groups during each condition of the task. (L-M (*SD*) and H-M (*SD*), respectively)

		TD (ms)	IA (%)	FC
ρ	a	0.43*	−0.12	0.38*
	b	0.30	−0.21	0.30
	c	0.29	−0.24	0.34*
M (*SD*)	a	1252 (492)	9.6 (6.8)	4.1 (1.6)
	b	703 (317)	56.8 (30.0)	1.9 (0.6)
	c	824 (378)	25.2 (18.7)	2.3 (0.8)
L-M (*SD*)	a	1024 (308)	10.4 (0.7)	3.3 (0.9)
	b	603 (194)	64.4 (27.1)	1.6 (0.4)
	c	700 (185)	30.4 (20.6)	2.1 (0.5)
H-M (*SD*)	a	1480 (542)	8.8 (6.1)	5.0 (1.8)
	b	804 (384)	49.6 (29.6)	2.1 (0.6)
	c	948 (477)	20.0 (15.6)	2.6 (0.9)
SB	a	0.96	0.58	0.95
	b	0.93	0.73	0.73
	c	0.99	0.76	0.97

TD, trial duration; IA, initial accuracy; FC, fixation count.
* Correlation is significant at the 0.05 level (two-tailed).

Table 2
Oculomotor variables measured during each condition of the visual search task

		FD (ms)	SL (°)	Lat (ms)	RPV
ρ	a	0.06	−0.12	−0.09	0.13
	b	0.19	−0.27	0.33	0.25
	c	0.14	−0.25	0.03	0.13
M (*SD*)	a	230 (43)	4.8 (0.9)	238 (84)	0.10 (0.05)
	b	251 (35)	4.4 (1.1)	184 (22)	0.04 (0.03)
	c	248 (41)	4.3 (1.1)	226 (37)	0.05 (0.03)
L-M (*SD*)	a	238 (54)	4.9 (1.0)	255 (109)	0.09 (0.04)
	b	251 (27)	4.6 (1.2)	179 (18)	0.03 (0.02)
	c	250 (42)	4.5 (1.0)	229 (42)	0.05 (0.03)
H-M (*SD*)	a	224 (28)	4.6 (0.9)	221 (46)	0.12 (0.06)
	b	252 (41)	4.1 (1.1)	188 (25)	0.04 (0.04)
	c	245 (42)	4.1 (1.1)	223 (33)	0.06 (0.03)
SB	a	0.91	0.90	0.99	0.96
	b	0.70	0.70	0.92	0.63
	c	0.72	0.67	0.88	0.81

FD, fixation duration, SL, saccade length; Lat, initial saccade latency; RPV, relative pupil variance.

Table 3
Performance-related variables measured during each condition (a, uninformed, color-discrepant condition; b, uninformed, orientation-discrepant condition; c, informed, color-discrepant condition; d, informed, orientation-discrepant condition) of the comparative visual search task

		TD (ms)	FC	CIFC	DS (°/s)	WM (objects)
ρ	a	0.59**	0.54**	0.33	−0.11	−0.29
	b	0.54**	0.50**	0.35*	−0.36*	−0.32
	c	0.36*	0.43*	0.31	−0.53**	−0.26
	d	0.47**	0.45**	0.39*	−0.13	−0.32
M (*SD*)	a	7272 (2330)	27.6 (8.7)	2.6 (0.4)	4.3 (2.2)	1.5 (0.7)
	b	9651 (3353)	36.4 (11.7)	2.6 (0.5)	4.1 (1.8)	1.2 (0.7)
	c	5827 (1976)	21.9 (6.9)	2.5 (0.4)	4.4 (1.7)	1.7 (0.8)
	d	8385 (3191)	31.6 (11.8)	2.5 (0.5)	4.0 (1.7)	1.3 (0.8)
L-M (*SD*)	a	6155 (1618)	23.4 (6.7)	2.5 (0.4)	4.0 (1.5)	1.7 (0.7)
	b	8174) (2071)	30.8 (9.1)	2.4 (0.4)	4.1 (1.2)	1.4 (0.5)
	c	5039 (1344)	18.6 (4.9)	2.4 (0.5)	4.9 (1.2)	1.9 (0.8)
	d	6927 (2293)	25.6 (8.2)	2.3 (0.4)	3.9 (1.2)	1.6 (0.8)
H-M (*SD*)	a	8389 (2434)	31.9 (8.5)	2.7 (0.3)	4.6 (2.8)	1.2 (0.6)
	b	11127 (3778)	42.0 (11.7)	2.8 (0.5)	4.0 (2.3)	1.0 (0.7)
	c	6616 (2219)	25.1 (7.2)	2.6 (0.3)	4.0 (2.0)	1.4 (0.7)
	d	9843 (3350)	37.6 (12.0)	2.8 (0.6)	4.1 (2.0)	1.1 (0.5)
SB		0.59	0.61	0.70	0.83	0.85
		0.72	0.67	0.69	0.89	0.61
		0.66	0.58	0.75	0.81	0.71
		0.69	0.68	0.48	0.54	0.74

TD, trial duration; FC, fixation count; CIFC, consecutive intra-hemifield fixation count; DS, descent speed; WM, working memory load estimate.
* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

Table 4
Oculomotor variables measured during each condition of the comparative visual search task

		FD (ms)	ISL (°)	Lat (ms)	RPV
ρ	a	0.16	0.00	0.26	0.05
	b	0.15	−0.04	0.10	0.04
	c	0.15	0.02	0.16	0.07
	d	0.18	−0.18	0.13	−0.09
M (*SD*)	a	215 (28)	3.9 (0.7)	159 (35)	0.31 (0.11)
	b	218 (30)	4.0 (0.7)	161 (42)	0.33 (0.13)
	c	216 (32)	4.0 (0.9)	155 (41)	0.26 (0.09)
	d	216 (31)	3.7 (0.8)	161 (44)	0.30 (0.09)
L-M (*SD*)	a	216 (32)	4.0 (0.8)	153 (32)	0.29 (0.10)
	b	221 (34)	4.0 (0.8)	158 (50)	0.32 (0.12)
	c	219 (38)	4.0 (1.0)	147 (46)	0.25 (0.09)
	d	220 (38)	3.7 (0.8)	158 (45)	0.30 (0.09)
H-M (*SD*)	a	214 (25)	3.9 (0.7)	166 (37)	0.32 (0.13)
	b	215 (26)	3.9 (0.7)	163 (33)	0.34 (0.15)
	c	213 (25)	3.9 (0.9)	164 (35)	0.27 (0.09)
	d	213 (21)	3.7 (0.8)	165 (43)	0.30 (0.10)
SB	a	0.94	0.94	0.70	0.63
	b	0.97	0.94	0.72	0.52
	c	0.94	0.92	0.91	0.57
	d	0.94	0.93	0.85	0.69

FD, fixation duration; ISL, intra-hemifield saccade length; Lat, initial saccade latency, RPV, relative pupil variance.

Table 5
Performance-related variables measured during each condition (a, uninformed, color-discrepant condition; b, uninformed, orientation-discrepant condition; c, informed, color-discrepant condition; d, informed, orientation-discrepant condition) of the visual memorization task

		Correct (%)	BFC	AFC
ρ	a	−0.34*	0.07	0.11
	b	−0.35*	0.01	−0.10
	c	−0.09	0.29	0.26
	d	−0.30	0.05	0.19
M (*SD*)	a	22.1 (25.5)	27.1 (5.2)	7.9 (4.1)
	b	22.6 (17.8)	27.6 (4.9)	9.5 (4.5)
	c	56.9 (27.6)	24.5 (5.4)	6.2 (4.3)
	d	33.3 (26.0)	27.4 (3.9)	7.6 (3.2)
L-M (*SD*)	a	28.4 (28.1)	26.1 (5.9)	7.9 (4.4)
	b	28.4 (15.3)	26.5 (5.5)	10.2 (5.0)
	c	59.8 (27.7)	22.9 (6.2)	5.8 (4.8)
	d	43.1 (28.9)	26.4 (4.4)	6.8 (3.5)
H-M (*SD*)	a	15.7 (21.6)	28.0 (4.3)	7.9 (3.9)
	b	16.7 (18.6)	28.6 (4.1)	8.9 (3.9)
	c	53.9 (28.0)	26.1 (4.1)	6.5 (3.8)
	d	23.5 (18.7)	28.3 (3.3)	8.3 (2.9)
SB	a	0.63	0.91	0.62
	b	0.29	0.91	0.55
	c	0.67	0.91	0.80
	d	0.52	0.88	0.45

Correct, percentage of trials answered correctly; BFC, before-switch fixation count; AFC, after-switch fixation count.
* Correlation is significant at the 0.05 level (two-tailed).

for condition, $F(2,64) = 77.48$, $p < 0.001$, and IT group, $F(1,32) = 253.75$, $p < 0.001$. A significant interaction between condition and IT group was also found, $F(2,64) = 4.32$, $p < 0.05$. The number of fixations per trial also correlated significantly with IT during the conjunctive-search condition, $\rho(32) = 0.38$, $p < 0.05$, and orientation-search condition, $\rho(32) = 0.34$, $p < 0.05$, but again only showed a correlation tendency during the color-search

Table 6
Oculomotor variables measured before the phase switch during each condition of the visual memorization task

		FD (ms)	SL (°)	Lat (ms)
ρ	a	−0.02	−0.00	−0.22
	b	−0.02	−0.12	−0.27
	c	−0.24	0.07	−0.27
	d	0.05	−0.00	−0.24
M (*SD*)	a	286 (96)	3.1 (1.0)	221 (95)
	b	281 (66)	3.3 (0.8)	208 (45)
	c	316 (117)	3.1 (1.0)	223 (126)
	d	281 (54)	3.3 (0.8)	218 (137)
L-M (*SD*)	a	306 (130)	3.1 (0.9)	249 (127)
	b	296 (85)	3.3 (0.9)	215 (52)
	c	346 (157)	3.0 (1.0)	251 (169)
	d	291 (68)	3.3 (1.0)	249 (186)
H-M (*SD*)	a	266 (33)	3.2 (1.0)	192 (30)
	b	267 (37)	3.2 (0.8)	202 (38)
	c	285 (44)	3.2 (1.0)	194 (47)
	d	272 (34)	3.3 (0.7)	186 (45)
SB	a	0.98	0.98	0.90
	b	0.95	0.96	0.07
	c	0.99	0.97	0.91
	d	0.96	0.97	0.96

FD, fixation duration; SL, saccade length; Lat, initial saccade latency.

Table 7
Oculomotor variables measured after the phase switch during each condition of the visual memorization task

		FD (ms)	SL (°)	Lat (ms)	RPV
ρ	a	−0.41*	0.04	−0.38*	−0.12
	b	−0.06	−0.06	−0.27	−0.17
	c	−0.39*	0.15	−0.20	0.00
	d	−0.35*	−0.03	−0.14	0.00
M (*SD*)	a	393 (164)	3.3 (0.8)	334 (147)	0.42 (0.26)
	b	339 (119)	3.3 (1.0)	309 (136)	0.39 (0.13)
	c	445 (213)	3.0 (0.8)	331 (132)	0.37 (0.18)
	d	342 (81)	3.4 (0.9)	286 (109)	0.36 (0.13)
L-M (*SD*)	a	448 (172)	3.3 (1.0)	392 (164)	0.41 (0.15)
	b	366 (151)	3.4 (1.1)	347 (168)	0.42 (0.14)
	c	515 (255)	2.9 (0.8)	341 (133)	0.35 (0.11)
	d	370 (93)	3.4 (1.0)	290 (136)	0.37 (0.11)
H-M (*SD*)	a	338 (141)	3.2 (0.7)	276 (102)	0.42 (0.33)
	b	313 (71)	3.3 (0.9)	270 (83)	0.35 (0.12)
	c	374 (136)	3.1 (0.7)	322 (134)	0.38 (0.24)
	d	314 (58)	3.3 (0.7)	281 (77)	0.36 (0.15)
SB	a	0.73	0.69	0.80	0.89
	b	0.62	0.86	0.24	0.44
	c	0.49	0.65	0.50	0.76
	d	0.43	0.89	0.30	0.85

FD, fixation duration; SL, saccade length; Lat, initial saccade latency, RPV, relative pupil variance.
* Correlation is significant at the 0.05 level (two-tailed).

condition $\rho(32) = 0.30$, $p = 0.05$. Participant's ability to locate the target object within their first fixation, which we will refer to as initial accuracy, was calculated as the percentage of trials where the distance between the target object and the participant's second fixation was less than or equal to 3°. Contrasting our hypothesis, initial accuracy did not correlate significantly with IT during the color-search condition, $\rho(32) = -0.12$, $p > 0.1$, orientation-search condition, $\rho(32) = -0.21$, $p > 0.1$, or conjunctive-search condition, $\rho(32) = -0.24$, $p > 0.1$.

None of the oculomotor variables we measured correlated significantly with IT during the visual search task. Fixation duration, which we speculated could be positively correlated with IT, did not show significance in doing so during the color-search condition, $\rho(32) = 0.19$, $p > 0.1$, orientation-search condition, $\rho(32) = 0.14$, $p > 0.1$, or conjunctive-search condition, $\rho(32) = 0.06$, $p > 0.1$. Furthermore, saccade length, which we speculated could be negatively correlated with IT, also did not show any significance during the color-search condition, $\rho(32) = -0.27$, $p > 0.1$, orientation-search condition, $\rho(32) = -0.25$, $p > 0.1$, or conjunctive-search condition, $\rho(32) = -0.12$, $p > 0.1$. The initial saccade latency variable, which is a measure of the amount of time between the onset of the trial display and the start of the first saccade, did however show a correlation tendency during the color-search condition, $\rho(32) = 0.33$, $p = 0.06$, but not the orientation-search condition, $\rho(32) = 0.03$, $p > 0.1$, or conjunctive-search condition, $\rho(32) = -0.09$, $p > 0.1$. The relative pupil variance measure, which does seem to reflect condition difficulty, also did not correlate significantly with IT during any of the task conditions (all $ps > 0.1$).

3.1.5. Discussion

In fitting with our hypothesis, participants in the low-IT group do appear to be able to locate the target object significantly more quickly than their high-IT counterparts during all task conditions; however, trial durations only correlated significantly with IT during the conjunctive-search condition, while they showed a tendency to correlate with IT during the feature-search conditions. It is interesting, given the simple nature of the IT task, that IT shows a significant correlation with the conjunctive-search condition but not with either of the feature-search conditions. A two-way ANOVA demonstrated that task condition does indeed interact significantly with the IT groups for trial durations. It seems likely though, that the correlations between IT and the feature-search conditions would reach significance if performed with a larger participant base. Still, the stronger correlation between IT and the more complex condition of the visual search task seems to be evidence that IT is indicative of more than a measure of the speed of sensory intake, and incorporates some measure of visual processing speed. Initial trial accuracy also did not correlate significantly with IT, despite the fact that there does appear to be a difference between participants in the low- and high-IT groups.

Interestingly, neither fixation duration nor saccade length correlated significantly with IT, which suggests that these variables are not dependant upon IT during our visual search task. However, saccade length does seem to vary somewhat with IT during the feature-search conditions, and the significance of these correlations may be hindered by the nature of the task; that is, the simplicity of the task is such that it does not require any systematic scanning pattern. However, a task that is designed to measure visual span, sometimes referred to as useful field of view, may in fact show such a correlation. A positive correlation tendency was found between IT and initial saccade latency during the color-search, which suggests that participants with a lower IT may be able to locate the target item more often in the initial fixation than participants with a higher IT.

4. Experiment 3: Comparative visual search task

Comparative visual search tasks have been shown to yield valuable insight into our use of visual working memory and visual–attentional control (Pomplun et al., 2001). For instance, Inamdar and Pomplun (2003) demonstrated that participants would increase the use of their visual working memory to compensate for more costly eye movements up to their visual working memory capacity. In this comparative visual search task presented here, participants were shown two nearly identical sets of objects (one object was dissimilar between the two sets) positioned on the left and right sides of the monitor. The two sets of objects were composed of the same oriented bars that were used in the visual search task. It was the participants' job to locate the single difference between the two sets of objects. The comparative visual search task used in the current study was designed to investigate differences in how low- and high-IT participants use their visual working memory and visual–attentional control to solve a task, and although there is no empirical link established between IT and visual working memory, the existence of one does not evade theoretical rationale.

4.1. Method

4.1.1. Participants and apparatus

The 34 participants that finished the IT task participated in the comparative visual search task. The apparatus from the visual search task served as the apparatus in the comparative visual search task as well.

4.1.2. Materials

Displays for the comparative visual search task were composed of the same oriented bars that were used in the visual search task. However, the displays for the comparative visual search task were composed of two sets of objects that were displayed on opposite sides of the display and divided by a single black line down the center of the display. We refer to the left and right sides of the display as the left and right hemifields. Each hemifield contained 20 objects that were composed of an equal number of the four different object types (i.e. five of each type). Objects were placed in each hemifield, which were of length 20.7° and width 11.9°, such that the minimum distance between the centers of any two objects was at least 2.6°; the hemifields were centered and separated by 5.5°. The two hemifields were identical except for a single discrepancy. A discrepancy occurred when an object from either hemifield had its color or orientation swapped; the discrepant object chosen was balanced across hemifields and vertical position; no distinction was made between the actual discrepant object chosen and its corresponding object from the opposite hemifield. The display categories were therefore defined by the dimension of the target object that was swapped, resulting in two categories of displays: color-discrepant displays (Fig. 3a); and orientation-discrepant displays (Fig. 3b). All displays were generated prior to starting the experiment so that every participant was subject to the same set of displays.

4.1.3. Procedure

Participants were given initial instructions about the nature of the experiment and their role in the task. They

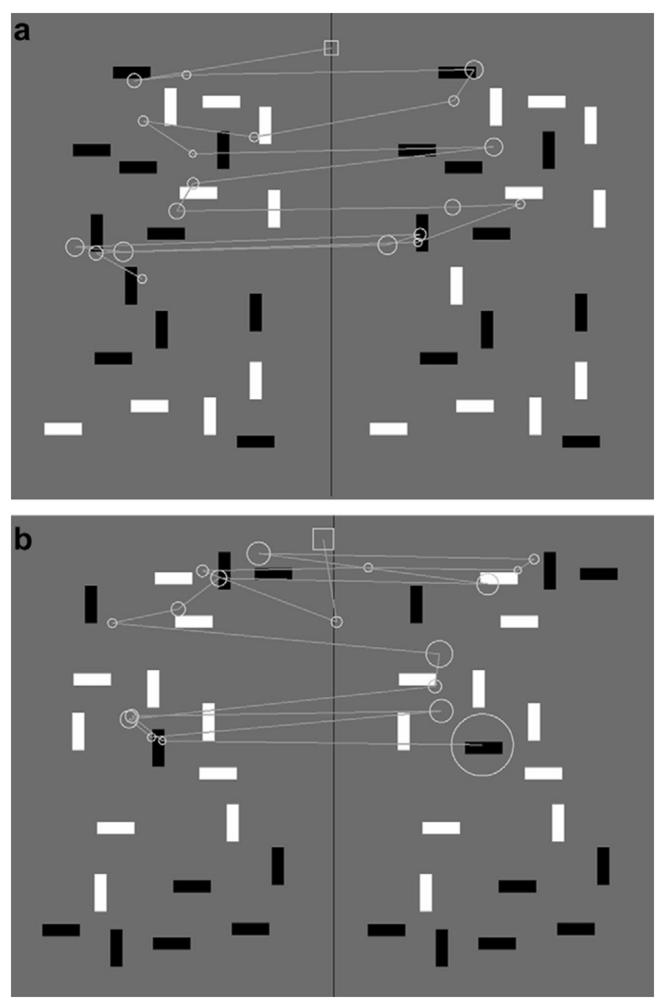

Fig. 3. Comparative visual search task images with sample eye movements of a participant superimposed on each: (a) example color-discrepant display. (b) Example orientation-discrepant display.

were instructed to locate the discrepancy between the two hemifields as quickly and accurately as possible, and to press a button on the game-pad while fixating on either object of the discrepancy. Participants were also instructed to serially search the display for the discrepancy starting at the top, and that if they had not located the discrepancy by the time they hit the bottom, to then search as they saw fit. Participants were tested under three trial conditions which were presented in blocks of 20 trials plus two training trials that were administered the first time a trial condition was presented. Prior to starting a block of trials, participants were shown a string of text that was used to indicate that the dimension of the discrepancy was either color, orientation, or unspecified for the following block; this led to the three trial conditions: the uninformed condition; the informed, color-discrepant condition; and the informed, orientation-discrepant condition. The uninformed condition was composed of an equal number of displays taken from the two display categories. The two informed conditions were composed solely of displays from their respective display categories. Participants were shown four blocks of displays, of which two blocks were uninformed; one was informed color-discrepant; and one was informed orientation-discrepant. The ordering of blocks and displays within each block were completely randomized except for the two training trials which were presented at the start of the blocks they were present in. Prior to the start of each trial, a drift correction similar to the one used in the visual search task was performed, except that the fixation point was presented at the top-center of the screen. Trials ended only after the button press indicating they were fixating on the target object.

4.1.4. Results

Trial accuracy for all participants was 2.9° with a standard deviation of 1.3°, and the rotated trial accuracy was 15.8° with a standard deviation of 1.1°. The significant difference between the trial accuracies, $t(33) = 35.62$, $p < 0.001$, demonstrates that participants were performing the correct task. Trial accuracy did not vary between IT group (low-IT: 2.9°; high-IT: 3.0°), $t(32) < 1.0$.

Trial durations for the comparative visual search demonstrated a significant correlation with IT at the 0.01 level during the uninformed, color-discrepant condition, $\rho(32) = 0.59$; uninformed, orientation-discrepant condition, $\rho(32) = 0.54$; and informed, orientation-discrepant condition, $\rho(32) = 0.47$, and a significant correlation with IT at the 0.05 level during the informed, color-discrepant condition, $\rho(32) = 0.36$. A three-way ANOVA with IT group (low IT vs. high IT) as a between-subject factor and information of the discrepancy dimension (uninformed vs. informed) and discrepancy dimension (color vs. orientation) as within-subject factors was performed for trial duration. Significant main effects were found for IT group, $F(1,32) = 11.92$, $p < 0.005$; dimension information, $F(1,32) = 24.75$, $p < 0.001$; and discrepancy dimension, $F(1,32) = 46.39$, $p < 0.001$, while no significant effects were found between factors (all ps > 0.1). The number of fixations per trial mimicked trial durations during the comparative search task, as they were found to correlate significantly with IT at the 0.01 level during the uninformed, color-discrepant condition, $\rho(32) = 0.54$; uninformed, orientation-discrepant condition, $\rho(32) = 0.50$; and informed, orientation discrepant condition, $\rho(32) = 0.45$, and at the 0.05 level during the informed, color-discrepant condition, $\rho(32) = 0.43$. The number of consecutive intra-hemifield fixations, which reflects the rate at which participants load and retrieve information to and from their working memory, also correlated significantly with IT during both the uninformed, $\rho(32) = 0.35$, $p < 0.05$, and informed, $\rho(32) = 0.39$, $p < 0.05$, orientation-discrepant conditions, but only showed a tendency to correlate with IT during the uninformed, $\rho(32) = 0.33$, $p = 0.06$, and informed, $\rho(32) = 0.31$, $p = 0.08$, color-discrepant conditions. The rate at which participants initially proceeded through each trial, referred to as descent speed, was also calculated. Since participants were instructed to compare objects in series from top to bottom, descent speed was calculated by dividing the vertical position of the target object by the amount of time it took participants to reach the target object's vertical area, which is defined as the center of the target object ±50 pixel-rows. Descent speed showed a significant negative correlation with IT at the 0.01 level during the informed, color-discrepant condition, $\rho(32) = -0.53$, and at the 0.05 level during the uninformed, orientation-discrepant condition, $\rho(32) = -0.36$. Additionally, an estimate of effective working memory load was also computed as the mean number of items located between successive inter-hemifield saccades to the same hemifield. Although the estimate of effective working memory load did not correlate significantly with IT during any of the task conditions, it did demonstrate a tendency to do so during the uninformed, color-discrepant condition, $\rho(32) = -0.29$, $p = 0.09$; uninformed, orientation-discrepant condition, $\rho(32) = -0.32$, $p = 0.07$; and informed, orientation-discrepant condition, $\rho(32) = -0.32$, $p = 0.07$.

As with the visual search task, oculomotor variables measured during the comparative visual search task did not correlate significantly with IT. Fixation duration again did not correlate significantly with IT during any of the conditions (all ps > 0.1). Saccade length was not directly measured during the comparative visual search task since the measure would be strongly influenced by the portion of saccades that were used to switch focus between hemifields, but instead, the intra-hemifield saccade length was measured, which is the mean length of the saccades that were made within the same hemifield. The intra-hemifield saccade length also did not correlate significantly with IT (all ps>0.1). Initial saccade latency also failed to correlate significantly with IT during all conditions (all ps > 0.1). Finally, relative pupil variance measures, although much greater during the comparative visual search task than during the visual search task, also did not correlate significantly with IT during any of the task conditions (all

$ps > 0.1$). The larger measures during the comparative visual search task are likely due to the required use of working memory during the task, as working memory has also been shown to influence pupil size (Kahneman & Beatty, 1966).

4.1.5. Discussion

As with the visual search task, participants with a lower IT also demonstrated a significantly greater ability to locate the target item more quickly during the comparative search task. Trial durations and the number of fixations made per trial during the comparative visual search task showed significant positive correlations at the 0.01 level for three out of the four task conditions, and although the correlations appear to be stronger during the more complex conditions of the task (i.e. the uninformed conditions), the information of the discrepancy's dimension did not show a significant interaction with IT group. Lower-IT participants' ability to locate the target item more quickly appears to be modulated, at least in part, by an ability to load and retrieve items to and from their working memory significantly more quickly; exactly which, or if both, cannot be determined by this particular task since participants are free to load and retrieve objects in any arbitrarily descending order. This is evidenced most strongly by the significant positive correlations between IT and the mean number of consecutive intra-hemifield fixations made per trial along with the tendency for the estimate of the effective working memory load to negatively correlate with IT.

The negative correlation tendency between IT and the estimate of effective working memory load, which may reach significance given a larger study, is in itself quite interesting. Inamdar & Pomplun (2003) were able to show that the effective working memory size during a very similar comparative visual search task was mediated by the 'cost' of inter-hemifield eye movements. This suggests that perhaps the cost of a working memory load of x items is lower for lower-IT participants than for higher-IT participants. Indeed, a case can be made for this. For instance, if working memory loading and retrieval time is a component of this cost, then the evidence previously presented suggesting lower-IT participants can load or retrieve items more quickly also suggests that the cost would be lower for lower-IT participants. Furthermore, a strong relation between working memory capacity and Spearman's g (general intelligence factor) has been theorized by a number of cognitive scientists (e.g. Conway, Kane, & Engle, 2003; Kyllonen, 1996), which may also lower this cost if there is a non-linear cost associated with larger working memory loads.

Finally, as with the visual search task, oculomotor variables measured during the comparative visual search task do not appear to be dependent upon IT. Similar moderately positive correlations between IT and fixation duration were found during each of the conditions for the comparative visual search as were found during the visual search task ($\rho \approx 0.15$). The intra-hemifield saccade length, as well as the initial saccade latency and relative pupil variance measures, did not show any significant correlation with IT.

5. Experiment 4: Visual memorization task

The visual memorization task and comparative visual search task presented here are quite similar except that the two sets of objects in the visual memorization task, which were again composed of oriented bars, were shown sequentially instead of simultaneously. This had the effect of placing a much larger burden on participants' visual working memory, as they were afforded only a single chance to load the objects into memory. What's more, the number of objects present in the displays largely exceeded the theorized visual working memory capacity. Consequently, participants needed to employ a higher-order cognitive strategy in order to perform the task accurately consistently. The case when participants were aware that the discrepancy dimension was color, in particular, lends itself very naturally to the strategy of perceptual grouping, and in the extreme case of the present task, participants were required to remember four overlapping groups of objects; clearly not only challenging their ability to form the perceptual groups (formation and application of a higher-order cognitive strategy), but also to remember the members of each group (visual working memory capacity).

5.1. Method

5.1.1. Participants and apparatus

The 34 participants that finished the IT task participated in the visual memorization task. The apparatus from the visual search task and comparative visual search task served as the apparatus in the visual memorization task as well.

5.1.2. Materials

Displays in the visual memorization task were composed of the same oriented bars that were used in the visual search task and comparative visual search task. In this task, two displays, temporally separated by one second, were presented to the participant. Each display contained 12 objects consisting of an equal number of objects from the four object types (i.e. three of each type). Objects were randomly placed in a screen-centered display area which had a length and width of 15.9°; the minimum distance between object centers was 3.4°. The two displays were exactly identical except for a single discrepancy which occurred when a random object in the second display had its color or orientation swapped. The display categories were therefore defined by the dimension of the target object that was changed; this resulted in two display categories: color-discrepant displays (Fig. 4a); and orientation-discrepant displays (Fig. 4b). All displays were generated prior to running the experiments so that each participant was subject to the same set of displays.

5.1.3. Procedure

Participants were first given instructions about the nature of the task and their role in it. Participants were then instructed to do their best to find the single discrepancy between the two displays that were presented each trial, fixate on the offending object in the second display, and press a button on the game-pad. If participants could not find the offending object, they were instructed to make their best guess. The first display of each trial was presented for eight seconds, followed by a gray, blank screen presented for one second, followed by the presentation of the second display. As such, each trial had two phases, a "loading phase", in which participants attempted to store the color of each object, orientation of each object, or both; and a "retrieval phase", in which participants attempted to locate the object that had its color or orientation changed. Trials ended only after participants pressed the game-pad button indicating they were fixating on what they believed was the discrepant object. Participants were tested using three trial conditions which were presented in blocks of 10 trials, except for the first time a trial condition was presented, which included two additional training trials. Prior to starting a block of trials, participants were shown a string of text that was used to indicate that the dimension of the discrepancy was either color, orientation, or unspecified for the following block; yielding the three testing conditions: the uninformed condition; the informed, color-discrepant condition; and the informed, orientation-discrepant condition. The uninformed condition was composed of an equal number of displays taken from the two display categories. The two informed conditions were composed solely of displays taken from their respective display categories. Participants were shown a total of four blocks, two of which were uninformed; one was informed color-discrepant; and one was informed orientation-discrepant. The ordering of blocks and displays within each block were completely randomized, except for the two training trials which were always presented first in the blocks they were present. Prior to the start of each trial, a drift correction identical to the one used in the visual search task was performed.

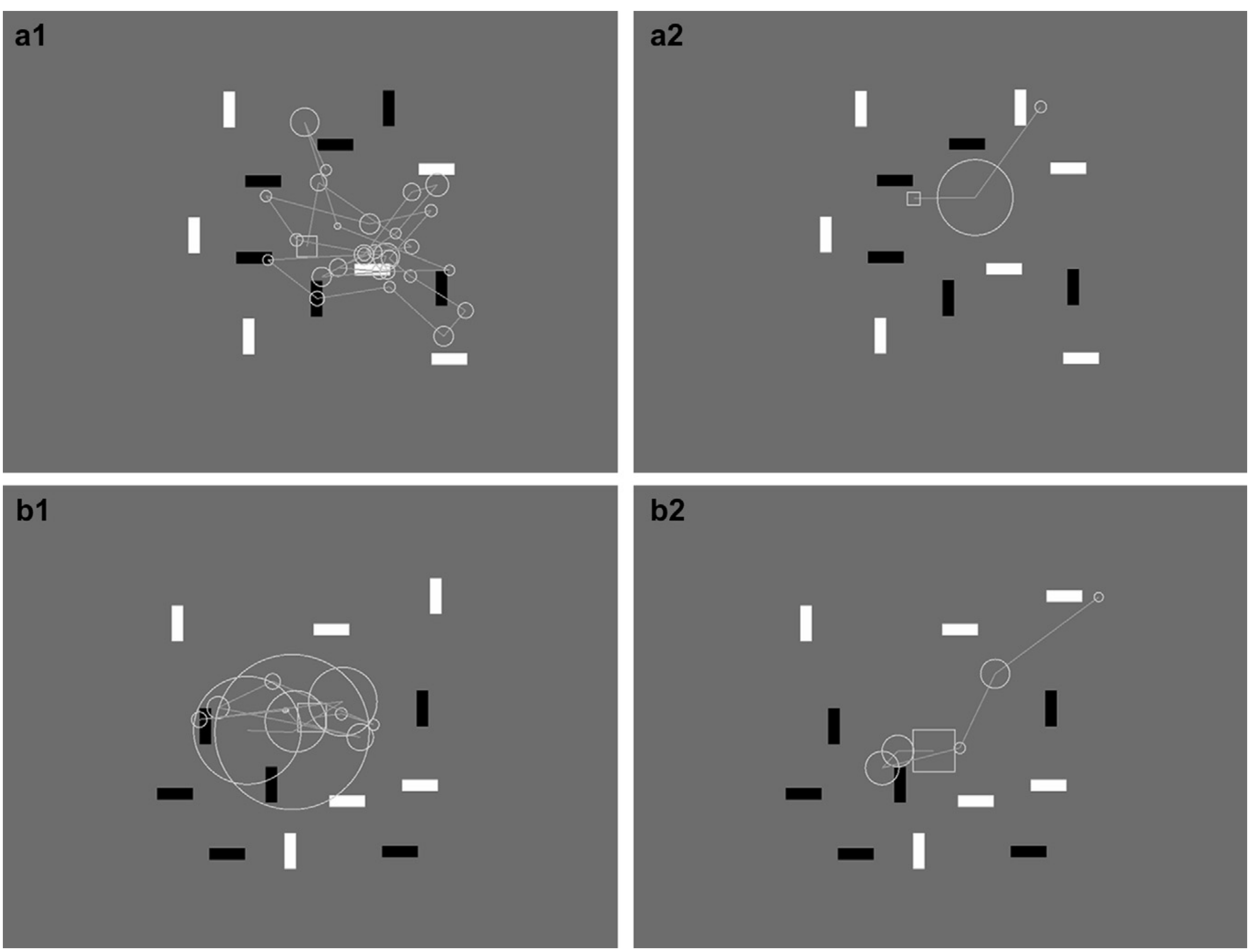

Fig. 4. Visual memorization task images with sample eye movements of a participant superimposed on each: (a) example color-discrepant display for both the loading phase (a1) and the retrieval phase (a2). (b) Example orientation-discrepant display for both the loading phase (b1) and retrieval phase (b2).

5.1.4. Results

Trial accuracy for all participants was 4.3° with a standard deviation of 1.1°, and the rotated trial accuracy was 8.2° with a standard deviation of 0.9°. The significant difference between the trial accuracy and rotated trial accuracy, $t(33) = 12.93$, $p < 0.001$, signifies that participants were performing the correct task. Trial accuracy for all conditions did vary significantly between participants in the low-IT group (3.9°) and participants in the high-IT group (4.7°), $t(32) = 2.1$, $p < 0.05$.

Significant negative correlations at the 0.05 level were found between the percentage of trials that were answered correctly and IT during the uninformed, color-discrepant condition, $\rho(32) = -0.34$; uninformed, orientation-discrepant condition, $\rho(32) = -0.35$; and tended to correlate negatively with IT during the informed, color-discrepant conditions, $\rho(32) = -0.30$, $p = 0.09$. A three-way ANOVA similar to that used during the comparative visual search task was performed for trial correctness. Significant main effects were found for dimension information, $F(1,32) = 71.04$, $p < 0.001$, and discrepancy dimension, $F(1,32) = 18.07$, $p < 0.001$, but only a tendency was found for IT group, $F(1,32) = 3.75$, $p = 0.06$. Only a single significant interaction was found between dimension information and discrepancy dimension, $F(1,32) = 13.16$, $p < 0.005$; this interaction appears product of the large drop in trial difficulty when the discrepancy dimension is known to be color, which is probably due the simpler perceptual grouping that is afforded during this condition. Trial durations were not analyzed for this experiment since their interpretation can be deluding (i.e. shorter response times can stem from two primary sources; that is, participants can either attain quicker trials from recognizing the discrepancy quicker or by not having any idea which is the discrepant object and arbitrarily guessing without searching).

Unlike the two previous tasks, the visual memorization task had two distinct phases: the loading phase and the retrieval phase. Consequently, the number of fixations made per trial and the oculomotor measures were divided into two categories: those made before the phase switch and those made after the phase switch. Neither the number of fixations made before the switch nor after the switch correlated significantly with IT (all ps > 0.1).

Oculomotor variables measured during the loading phase of the visual memorization task, as with the two previous tasks, did not correlate significantly with IT during any of the conditions. If a difference was observed during the loading phase of this task, it would likely signify a difference in memorization strategy. Fixation duration along with saccade length before the phase switch showed no significant correlation with IT (all ps > 0.1). Initial saccade latency, despite not correlating significantly with IT, did show a consistent negative correlation of around −0.25 for all conditions, which may signify a slight difference in initial planning strategies between lower-IT participants and higher-IT participants.

Some oculomotor variables measured during the retrieval phase do correlate significantly with IT. In particular, fixation durations measured after the phase switch show a significant negative correlation with IT during the uninformed, color-discrepant condition, $\rho(32) = -0.41$, $p < 0.05$; informed, color-discrepant condition, $\rho(32) = -0.39$, $p < 0.05$; and informed, orientation-discrepant condition, $\rho(32) = -0.35$, $p < 0.05$. Saccade length, as before, does not correlate significantly with IT (all ps > 0.1). Initial saccade latency following the phase switch only showed a significant negative correlation between IT during the uninformed, color-discrepant condition, $\rho(32) = -0.38$, $p < 0.05$. Finally, relative pupil variance measured during the entire trial did not vary significantly with IT (all ps > 0.1).

5.1.5. Discussion

Unlike the previous two tasks, the primary performance variable during the visual memorization task was not trial duration but trial correctness. In general, it appears that lower-IT participants do perform better at the visual memorization task, but trial correctness only demonstrated a significant negative correlation with IT during the uninformed conditions of the task, and tended to correlate negatively during the informed, orientation-discrepant condition. As with the two previous tasks, it again appears that correlations are stronger during the more complex conditions of the visual memorization tasks, and that the lack of correlation during the informed, color-discrepant condition is due to a floor effect.

Up to this point, oculomotor measures have not differed between participants with low and high ITs. Interestingly, the differences occur during the retrieval phase of the task. This suggests that lower- and higher-IT participants did not, for the most part, deviate in their application of a memorization strategy, but instead, deviated significantly in their either their success at memorizing the objects or the memorization strategy used during the loading phase. As such, we speculate that the longer initial saccade latency and fixation durations during the retrieval phase for the low-IT group stem directly from participants in the low-IT group retrieving and comparing larger or more complex pieces of information per fixation because of a greater success at applying a higher-level memorization strategy. The lack of a significant correlation during the uninformed, orientation-discrepant condition is likely due to the large difficulty in memorizing all the information needed for this condition.

6. Conclusions

ITs were first recorded from participants using a variation of the standard IT task. In the three visual tasks that followed the IT task, we found that participants who were adept at performing the IT task (those with lower ITs) possess significantly greater performance capabilities than do participants who were less adept at performing the IT task (those with higher ITs). Superior performance capabilities were found during the visual search task and comparative visual search task in the form of significantly shorter trial durations under all testing conditions. In both tasks, IT correlated more significantly with the more complex conditions of the task; however, a significant interaction between IT group and task condition was only present for the visual search task, which is likely a result of the larger gap for mean trial durations between the low- and high-IT groups for the conjunctive-search condition than either of the feature-search condition (conjunctive-search: 456 ms; color-search: 201 ms; orientation-search: 248 ms). This would seem to suggest that IT is more than a simple measure of the speed of information intake, but instead also incorporates some low-level visual processing abilities. This result does not come as much of a surprise since IT has been theorized by some researchers to be a measure of visual processing speed.

Correlations between trial duration and IT were stronger for the comparative visual search task than for the visual search task, as all but the informed, color-discrepant condition correlating at the 0.01 level. Although the Spearman–Brown reliability values were more modest for comparative visual search trial durations ($\sim$0.67), it seems clear that large performance differences do exist between participants with low and high ITs. These differences appear to be, in part, due to an ability of lower-IT participants to load or retrieve objects to or from their working memory more quickly than higher-IT participants. Furthermore, estimates of effective working memory load during the comparative visual search task tended to correlate negatively with IT ($\rho s \approx -0.30$), which may be due to a decreased cost associated with higher working memory loads for lower-IT participants. In either case, future research is certainly merited to probe the relationship between IT and effective working memory load.

Finally, in the visual memorization task, lower-IT participants showed a greater ability to locate the target object through a significantly higher trial correctness measure. However, the percentage of trials correctly responded to only correlated significantly with IT during the uninformed conditions of the task. Given the results from each of the three visual tasks administered, it is clear that IT is associated with certain visual abilities, which seems to almost certainly include speed of sensory information intake and lower-level visual processing abilities. Additionally, IT also seems to function as a predictor of other cognitive abilities, which, indicated by our results, may include the speed of working memory storage and effective working memory load size.

In our hypothesis we predicted that IT may correlate significantly with certain oculomotor measures during the visual tasks we presented. In particular, we hypothesized that a negative correlation with saccade length may exist if lower-IT participants are able to process a larger area of the displays, or conversely, a positive correlation with fixation duration may exist if lower-IT participants are able to process stimuli more quickly. In the tasks that we presented, we found no significant evidence of such a relationship. In fact, the only correlations between IT and the oculomotor measures we recorded were found during the retrieval phase of the visual memorization task. Why though, are there oculomotor differences related to IT during this task and not the other two? To answer this we must first examine the question, what are the differences between this task and the previous two? The visual memorization task deviates in two primary ways. One, unlike the visual search task and comparative visual search task, task performance for the visual memorization task is not evaluated using response time. The lack of time pressure may prevent participants from following a systematic foveal analysis. Two, for the visual memorization task to be performed accurately, consistently, the participant must successfully formulate and apply a higher-level cognitive strategy since the number of individual objects greatly exceeds the visual working memory capacity. This in itself could contribute significantly to the correlations found, and in particular, is advocated by the fact that the differences between the IT groups come during the retrieval phase. These differences between the lower- and higher-IT participants during the retrieval phase of the visual memorization task provides compelling evidence for a divergence in cognitive processes due to either a difference in participants' ability to memorize objects during the loading phase, or a difference in the memorization strategy employed.

Despite the fact that we were unable to find significant evidence that the oculomotor variables we measured are mediated by IT, these variables do not seem to be completely unrelated. It seems instead that under certain circumstances these measures may in fact correlate significantly with IT. For instance, a task that is designed specifically to measure participants' visual span, also known as useful field of view, may demonstrate a significant correlation with IT. Furthermore, a correlation between fixation duration may exist in a situation where the amount of information in a particular location is specifically controlled for. We therefore speculate that these variables could in fact correlate significantly with IT during our everyday vision, but most likely only in situations where a systematic benefit would be realized. Our future research will therefore address this question among others.

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