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Short report

Overlap between visual inspection time tasks and general intelligence

Cathal McCrory *, Colin Cooper

School of Psychology, The Queen's University, Belfast BT7 1NN, United Kingdom

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Abstract

The stimulus display duration required for subjects to accurately compare the length of two line lengths (known as Inspection Time: IT), reliably correlates around 0.5 with general intelligence. It is not clear, however, if this correlation reflects general “speed of processing”, or some other element of the task. There is a consequent need for new experimental paradigms. We describe a novel IT task where participants viewed a sequence of eight briefly-presented coincident coloured circles, the first of which was presented for a variable duration. Participants reported the colour of the first circle. The threshold for perceiving this colour correlated 0.37 and 0.38 ($p<0.05$) with two conventional IT tasks within a sample of 75 students. It also correlated significantly with scores on a timed measure of the Raven’s Advanced Progressive Matrices ($r=-0.39$, $p<0.01$). The implications of these results for the validity of the concept of IT are discussed.

Keywords: Intelligence; Inspection time; Cognitive ability; Mental abilities

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1. Introduction

There is little doubt that Inspection Time (IT) is related to psychometric intelligence at about the level of −0.5 (Grudnick & Kranzler, 2001), though at present it is unclear whether IT is most closely aligned with *g* or some broad secondary such as general speediness (Burns & Nettelbeck, 2003; Burns, Nettelbeck, & Cooper, 1999) or a perceptual/organisation factor (Crawford, Deary, Allan, & Gustaffson, 1998). That performance on a *simple* two-choice forced discrimination task should correlate so strongly with ability has naturally prompted speculation that IT may be tapping low-level physiological processes that are causal to intelligence, with neuronal speed widely touted as the pathway conveying these individual differences in ability.

The search for a mechanism underlying the association has opened up some promising lines of inquiry. Pharmacological studies involving the modulation of important neurotransmitters and receptor sites in the brain suggest that the cholinergic system may provide a biological basis for IT (Stough, Thompson, Bates, & Nathan, 2001); while the results of a preliminary functional brain imaging study indicates activation in brain areas during IT performance that are common to those involved in psychometric test performance (Deary et al., 2001). Although an initial paper by Posthuma and colleagues provided tentative support for the idea that the correlation between IT and

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* Corresponding author.
E-mail addresses: cathal.mccrory@esri.ie (C. McCrory), c.cooper@qub.ac.uk (C. Cooper).

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intelligence is genetically mediated (Posthuma, de Geus, & Boomsma, 2001), a subsequent study suggests that IT is neither causal to, nor a consequence of IQ: but rather, that a common genetic factor influences variation in both (Luciano et al., 2005).

These concerns regarding the locus of the IT–IQ association echo previous criticisms that have been directed at the IT procedure. For one thing, the sensitivity of IT measures to cognitive strategies (see Alexander & Mackenzie, 1992) has left the task open to the charge that IT is just another high level task that intelligent people perform well. Although the issue of strategy use has been extensively examined, and found to be an inadequate explanation for the correlation between IT and *g*, the existence of practice effects suggests that at least some aspect of learning may be involved. Bors and MacLeod (1996) for example, measured participants IT over three successive days and reported a diminution of the IT–IQ correlation from −0.43 on day one to −0.07 (n.s.) on day three (see also Stokes & Bors, 2001).

Rather fewer studies have explored whether different putative measures of IT measure the same construct. Doing so is important in order to establish the construct validity of IT tasks. Whilst it is commonly assumed that performance on an IT task reflects some basic biological process such as nerve conduction velocity, it is possible that some task-specific individual differences, skills or strategies (such as individual differences in visual memory, susceptibility to masking or altering the fixation point so as to better detect flicker off the fovea) will also affect performance on a particular measure. Without administering several different tasks (each with different cognitive demands), it is difficult to determine the extent to which such specific skills influence the correlation between task performance and intelligence. In the spirit of previous research varying the mask (Stough, Bates, Mangan, & Colrain, 2001), the effect of strategy (Stough, Bates et al., 2001; Stough, Nettelbeck, Cooper & Bates, 1995), the stimulus modality (Deary, Head, & Egan, 1989; McCrory & Cooper, 2005), and the task itself (Vickers, 1995) we are using a new variant to explore the basis of the IT–IQ correlation.

Although a few attempts have been made to broaden the experimental scope of the task (see below), the great majority of studies employ the conventional two-lines discrimination, or minor variants such as Nettelbeck and Kirby's (1983) 2-lights version which used LEDs as the discriminatory stimulus. Anderson (1986) attempted to increase the ecological validity of the task by embedding the stimuli within a space invaders game; while an alphanumeric version of the task developed by Bowling and Mackenzie (1996) seems to confound processing speed with verbal ability. These investigators found that while the traditional task correlated significantly with both verbal and non-verbal scores from the Differential Aptitude Test, the alphanumeric version shared significant associations with only the verbal scale. More recently, Frings and Neubauer (2005) report the results of a study in which participants had to judge the valence (positive or negative) of words that were displayed for a variable duration and masked using strings of consonants. They found that performance on this task was significantly correlated with measures of ability across two separate studies, leading these authors to conclude that the mechanism underlying the IT–IQ correlation may be independent of the complexity of stimuli (see also Burns, Nettelbeck, & White, 1998; Nettelbeck, 2001). The recent visual detection tasks developed by Deary (1999) are not treated here as they involve no masking component and seem to emphasise broader attentional processes.

We argue that this is a general failing in the IT literature and is important for a number of reasons. Levy (1992) for example has expressed misgivings concerning the experimental symmetry of different IT procedures, drawing attention to the fact that when IT is estimated using 2 lights or segmented LED displays (e.g. Kranzler and Jensen, 1991) it yields correlations with ability that are routinely lower than those reported using tachistoscopic or computer screen displays. Moreover, in the very few instances where IT has been assessed using different tasks across the same sample of participants, cross-task correlations raise concern as to whether they tap the same underlying construct. Burns and Nettelbeck (2003) reported a correlation of 0.29 between performance on a two-lines and LED version of the task, while an alphanumeric version correlated 0.36 and 0.35 with each of the tasks respectively. It is quite possible therefore that the various tasks being used to assess visual processing speed are tapping task specific rather than *g*-related variance.

As White (1993, 1996) has argued that IT is only one of a number of pattern backward masking paradigms that could, and theoretically should, correlate with ability, the present paper represents an attempt to develop and extend the number of paradigms used in visual IT research. We chose tasks that imposed similar processing demands to the conventional IT task but involve different discriminatory stimuli. It is expected that each of the IT tasks (described below) will be inversely related to cognitive ability. It is further anticipated that the alternate versions of IT will be significantly positively inter-correlated, as one would expect if they are indeed indexing the same underlying process.

2. Method

2.1. Participants

75 participants (22 male, 53 female) with mean age = 20.14 years (S.D. 3.4) undertook three visual IT tasks alongside a series of cognitive ability measures. Most were students, and the sample had a mean IQ of 114 (S.D. 8.2) according to the Multidimensional Aptitude Battery. All subjects had normal or corrected to normal vision as measured under standard conditions using a Snellen chart. It was unnecessary to screen for colour blindness, as practice trials would identify colour-blind individuals.

2.2. Cognitive ability measures

All participants completed the Multidimensional Ability Battery II (MAB; Jackson, 1998) which yields separate verbal and performance scales, as well as a full scale IQ measure. The number-checking scale from the Ekstrom, French, Harman and Derman (1976) kit was also included as an independent measure of perceptual speed. This was supplemented by Books I & II of Raven's Advanced Progressive Matrices (RAPM; Raven, 1965) which is heavily *g*-loaded. The time limits for the RAPM were 30 min for the short version, while Book 2 was given as a power test and had no time restrictions.

2.3. Equipment

The IT tasks were written in-house using Acorn Basic VI software and ran on an Acorn RISC-PC microcomputer with colour monitor. This system allowed direct control over the refresh rate of the monitor, and the available hardware was able to support a vertical refresh rate of 137 Hz. The stimulus levels employed were therefore in exact multiples of the screen refresh time of 137 Hz, which equates to increments of 7.3 ms. The software switched between banks of pre-drawn screen memory in order to allow very fast stimulus presentation.

2.4. Procedure

Participants sat three computer-based IT tasks. The first involved the traditional pi-stimulus IT procedure (cf. Nettelbeck, 1987), which required a comparative judgment concerning whether the longer leg of a target figure occurred on the right or left hand side of a stimulus display. The longer line was 70 mm long; the shorter was 40 mm and the distance between the lines was 32 mm. The stimuli were masked using broader lines 100 mm long. We used the conventional mask because we wanted to explicitly test the hypothesis that the IT–IQ correlation arises because intelligent people use strategies to obviate the deleterious effects of the mask.

The second task has not been previously used or described in the literature. Participants saw eight 100 mm diameter coloured circles displayed sequentially in the same location on a computer screen. Participants identified the colour of the first circle shown, the duration of which was varied in order to determine the threshold at which this discrimination was possible. Four colours were used (green, yellow, blue, red) and the order of the last seven 'masking' circles was determined at random. Each of the masking circles was displayed for 7.3 ms. The only proviso was that no two successive circles were the same colour. Each of the masking circles was displayed for 7.3 ms. A circle was chosen as the target stimulus in an attempt to overcome problems of apparent motion evident with the traditional IT task. The luminance of the target colours was calibrated during pre-testing by having participants match the colours for apparent brightness. Participants sat approximately 40 cm from the screen display at a screen luminescence of 3.5 cd/m^2.

The final task, which was adapted from the work of Nettelbeck and Kirby (1983) required participants to attend to an array of eight red light emitting diodes (LEDs) each 5 mm in diameter, which were mounted horizontally 10 mm apart on a blue painted board inclined at 30° to attenuate reflectance. The apparatus was controlled by an Acorn RISC-PC microcomputer running a millisecond timer. A green warning light signalled the beginning of each trial and after a period of 1 s had elapsed, one of the lights was illuminated slightly before the others, the interval being determined adaptively (Lieberman & Pentland, 1982). Respondents indicated which light was illuminated first using a keypad.

For each of the three tasks, participants were given 10 practice trials at the highest stimulus duration of 210 ms and the entry criterion was 90% correct responding. Two participants were unable to complete the hurdle for the circles task

Table 1
Correlations between inspection time and cognitive measures (two tailed)

	Circles	Lights	Verbal IQ	Performance IQ	Full scale IQ	Raven 1 (timed)	Raven 2 (untimed)	Perceptual speed
Lines $n=75$	0.38*	0.56***	−0.40**	−0.25	−0.36*	−0.41**	−0.44**	−0.12
Circles $n=73$		0.37*	−0.30	−0.11	−0.22	−0.39**	−0.31	−0.25
Lights $n=75$			−0.22	−0.19	−0.23	−0.24	−0.21	−0.07
Mean standardised threshold			−0.37*	−0.18	−0.30	−0.42**	−0.38*	−0.17
Verbal IQ				0.61***	n/a	0.58***	0.60***	0.18
Performance IQ					n/a	0.56***	0.62***	0.25
Full scale IQ						0.63***	0.69***	0.25
Raven 1							0.56***	0.29
Raven 2								0.25

Significance levels are two-tailed and conservative, controlling for familywise error rate by the multistage Bonferroni (Bonferroni Holm) adjustment.
*$p<0.05$, **$p<0.01$, ***$p<0.001$.

due to colour blindness. Responses were made using a hand held response box and the importance of accuracy over speed was emphasised throughout. Each main task comprised 70 trials and exposure level was determined using an adaptive staircase procedure (Lieberman & Pentland, 1982). A curve-fitting program developed by the second author estimated the duration of the threshold of each person for each task at a point half way between chance and perfect performance. See McCrory and Cooper (2005) for details of this procedure. Upon completion of each of the tasks participants were quizzed concerning strategy use. Following Langsford, Mackenzie, and Maher (1994), this consisted of a simple probe question of the form "How could you tell?" Written responses were examined and participants were categorized as users or non-users respectively.

3. Results

Table 1 shows the correlation between Inspection Time and cognitive measures (two-tailed). Significance levels are two-tailed and conservative, controlling for familywise error rate by the multistage Bonferroni (Bonferroni Holm) adjustment.

Regression of the lines task on FSIQ [R^2 change$=0.066$; F change $(1,71)=4.997$, $p<0.01$] revealed that little additional information was obtained by adding the circles [R^2 change$=0.010$; F change $(1,70)=0.761$, $p>0.05$] and lights [R^2 change$=0.002$; F change $(1,69)=0.116$, $p>0.05$] tasks at the second and third stages of the model. A principal components analysis (PCA) of the three visual IT tests indicated that each of the tasks had a large and significant loading (lines 0.84; circles 0.65; lights, 0.81) on a latent Visual IT factor (accounting for almost 60% of the variance).

A canonical correlation was also carried out to determine how much of the variance in a weighted sum of the inspection tasks could be explained by a weighted sum of the cognitive measures. One canonical variate was significant (0.60: $p=0.002$) and Table 2 shows the cross-loadings for the two sets of variables.

4. Discussion

As predicted, the correlations between the IT tasks were all positive and significant, ranging from 0.37 to 0.56. The results of the PCA indicated that each of the IT tasks had a large and significant loading on a latent Visual IT factor which points to substantial overlap between tasks. The hierarchical regression indicates that no significant additional information is gained by adding the circles and lights tasks to the model. Collectively, this pattern of results suggests

Table 2
Cross-loadings on the first discriminant function for four cognitive variables and three measures of inspection time

	VIQ	PIQ	Raven 1	Raven 2	Lines	Circles	Lights
Cross-loading	0.376	0.142	0.461	0.462	−0.520	−0.416	−0.178

that some variable or variables (possibilities include neural conduction velocity, cognitive processes or strategy use) that are common to all tasks influences performance on each.

The correlations between the three IT tasks and the various measures of psychometric ability are all negative, and many are significant even though the Bonferroni–Holm adjustment tends towards conservatism. The two-lines task was found to be significantly related to FSIQ ($r=-0.36$, $p<0.05$) while the corresponding associations were ($r=-0.22$, $p>0.05$) and ($r=-0.23$, $p>0.05$) for the circles and lights task respectively. The magnitude of the uncorrected IT–IQ correlations reported here are comparable to those found by Burns and Nettelbeck (2003) for a two-lines (−0.33) and segmented LED (−0.19) version of the task with the Woodcock Johnson battery. After correction for range restriction however, the correlation of IT with FSIQ was ($r=-0.58$, $p<0.001$), ($r=-0.38$, $p<0.05$) and ($r=-0.40$ $p<0.01$) for the lines, circles and lights tasks respectively. This indicates that fast inspection times are associated with high levels of cognitive ability even without attempting to correct for the reliability of the experimental measures. A composite measure calculated by summing the three standardised visual IT thresholds correlated −0.30, ($p>0.05$) with FSIQ before correction for range restriction, −0.50 after ($p<0.001$) which accords with Grudnick and Kranzler's (2001) meta-analytic estimate of the extent of the relationship.

Interestingly, all three IT tasks demonstrated higher correlations with verbal ability than they did with the performance measure. This conflicts with the results of previous meta-analytic reviews which have reported larger associations with performance as opposed to verbal measures (e.g. Kranzler & Jensen, 1989; Nettelbeck, 1987). The reasons for this are not immediately apparent, though Crawford et al. (1998) and Mackintosh (1998) have noted that the WAIS-R, from which the MAB was derived, produces a general factor that is rather biased towards verbal components. In addition, Fisher's z-test for two independent correlations revealed that the IT–VIQ coefficients were not significantly different than the corresponding IT–PIQ coefficients. The canonical correlation indicates that the Verbal IQ and both Raven's Matrices scores are substantially correlated with the lines and circles IT tasks. Moreover, a general ability factor extracted from the MAB correlated −0.32 ($p>0.05$) with the Visual IT factor prior to correction, −0.53 after ($p<0.001$). This suggests that general ability to perceive shapes quickly accounts for a reasonable portion of the variance in g.

Participants were asked about any strategies which they used to help them solve the tasks. 81% of participants used a strategy on the lines task as opposed to 27% and 43% for the circles and lights task respectively. Although cue users recorded shorter thresholds on each of the lines and lights task, examination of the distribution of IQ scores revealed no significant differences between groups. This suggests that the correlations do not arise simply because high ability participants are cue-users (cf. Egan, 1994). Nor does it seem that the association is mediated by perceptual speed, as the derived Visual IT factor was more highly correlated with g ($r=-0.32$) than it was with the independent (number checking) perceptual speed measure ($r=0.28$).

Apart from further strengthening support for a neural speed interpretation of g, the results of the present study suggest that the processes being tapped by IT are amenable to investigation via other tests, involving somewhat different cognitive processes. The circles test required participants to observe and remember the first colour in a sequence: the lines test assessed ability to process the length of two lines presented concurrently, and the LED task required participants to monitor an array of lights and make a temporal discrimination. Although the circles task was less strongly associated with the various measures of cognitive ability than the two-lines version, we believe that it represents a useful addition to the IT task repertoire and supports White's (1996) contention that the two-lines task has no special status in relation to IQ. Developing variants on the traditional two-lines procedure is necessary not only to establish the construct validity of IT, but also to rule out an artificial explanation for the association (e.g., task specific abilities, strategy use). Future research would benefit from an attempt at replication, particularly with respect to the new colour based discrimination task.

Results suggest that IT is measuring a latent information processing parameter that is related (and possibly causal) to g; and biological studies have generated a number of interesting leads in terms of identifying a mechanism underlying the association. Candidates include the degree of myelination of cerebral nerve fibres (Miller, 1994), and a role for the cholinergic system (Stough, Thompson et al., 2001). Future research would benefit from an attempt to determine whether the processing speed being tapped by visual IT is comparable to that captured by auditory IT and other purported information processing measures (e.g. reaction time, odd-man-out), though results to date have not been impressive (see for example, Burns & Nettelbeck, 2003). Furthermore, it could be argued that if we are to advance our understanding of the task beyond asserting that a simple correlation exists, it is imperative that we begin to vary the procedural requirements and task parameters to set limits on our theorising concerning the generality or otherwise of this vaguely operationalised 'mental speed' concept.

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