Intelligence 37 (2009) 76–80

Contents lists available at ScienceDirect

Intelligence

Reversing the speed–IQ correlation: Intra-individual variability and attentional control in the inspection time paradigm

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ARTICLE INFO

Article history:
Received 23 April 2008
Received in revised form 1 August 2008
Accepted 1 August 2008
Available online 13 September 2008

Keywords:
Intelligence
IQ
Inspection time
Dual task
Attention
Intra-individual variability

ABSTRACT

Elementary cognitive tasks (ECTs) are simple tasks involving basic cognitive processes for which speed of performance typically correlates with IQ. Inspection time (IT) has the strongest IQ correlations and is considered critical evidence for neural speed underlying individual differences in intelligence. However, results from Bors et al. [Bors, D.A., Stokes, T.L., Forrin, B. & Hodder, S.L., (1999). Inspection Time and Intelligence: Practice, strategies, and attention. Intelligence, 27, 111–129.] suggest task consistency may underlie this shared variance. One possibility is that performance consistency reflects attentional mechanisms, as previous research has shown relationships between attentional control and cognitive performance. In study 1, participants were administered the Raven's Advanced Progressive Matrices and performed an alternative version of the IT task to measure individual trial-by-trial consistency expressed as the standard deviation of IT (ITSD). The alternative procedure yielded IT–IQ correlations similar to those obtained in previous studies and ITSD accounted for the IT–IQ variance. A second experiment tested whether ITSD measures attentional control, as participants simultaneously performed the IT task and an attention-demanding verbalization task. Under these conditions, high IQ participants performed worse on IT. These results suggest IT performance may reflect individual differences in attentional control and that this variable may account for the variance shared between IT and IQ.

Intelligence researchers have long considered processing speed to be a critical component of IQ (Eysenck, 1987; Jensen, 1993), often describing individual differences in cognitive performance across a range of tasks as a function of the inherent speed and efficiency of the nervous system (Eysenck, 1987; Jensen, 1993). Critical findings underlying these theories come from studies reporting negative correlations between reaction-times (RT) from elementary cognitive tasks (ECTs, typically timed tasks of very low difficulty said to reflect basic cognitive processes) and IQ (Vernon & Jensen, 1984). However, other studies suggest that variability on ECTs also tends to correlate with IQ (Jensen, 1992); moreover, others have reported findings suggesting individual differences in attentional control may give rise to variability on cognitive tasks (e.g. Colflesh & Conway, 2007; Conway, Cowan & Bunting, 2001). An intriguing possibility is that attentional control is one avenue through which individuals of high cognitive ability exhibit faster performance on ECTs. While this possibility does not dismiss the role of neural speed, it suggests these influences may be less direct. The principal aim of the present study is to determine whether individual differences in attentional control influence inspection time (IT)—the ECT considered most critical for speed theories of IQ.

Among ECTs, IT yields the highest correlations with IQ, shares variance with IQ that is independent of other ECTs (Petrill, Dasen, Thompson & Detterman, 2001), and is thought to measure perceptual speed (Deary & Stough, 1996, Mackintosh & Bennet, 2002). IT is a two-choice perceptual discrimination task in which participants attempt to determine which of two briefly presented parallel lines is shortest. The briefest stimulus duration, or stimulus onset asynchrony (SOA), at which a participant can achieve a given accuracy rate (typically between 70% and 95%) is the participant's

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doi:10.1016/j.intell.2008.08.002

threshold-IT. The task is central to speed theories of intelligence, given that motor movement does not confound estimated IT and that IT tends to yield the highest correlations with IQ among ECTs. In a recent meta-analysis featuring 90 studies, Grudnick and Kranzler (2001) report an uncorrected correlation of −.30 between IT and IQ (that increased to −.51 after correcting for artifacts of sampling and measurement error and restriction of range).

In contrast to neural efficiency theories, several researchers have suggested IT may reflect higher-level cognitive processes such as strategy use (Mackintosh, 1986) and attentiveness (e.g., Bors, Stokes, Forrin & Hodder, 1999; Stokes & Bors, 2001). The most frequently reported strategy described is an apparent-motion strategy (Mackintosh, 1986), where participants observe an apparent-motion caused by the appearance of the masking stimulus over the two differentially long lines. However, evidence suggests that variance between IT and IQ may be non-strategic, given that the correlation is strongest in samples not reporting strategy use (e.g., Egan & Deary, 1992; Grudnick & Kranzler, 2001), and that strategy users do not achieve higher IQ scores (MacKenzie & Bingham, 1985). Notably, use of strategies are determined by self-report, and investigators have not yet found an external source of validation that these participants are, in fact, performing the task differently.

Bors et al. (1999) argue that "attentiveness" or "participants' ability to remain focused trial by trial on the task" (p. 123), contributes to the IT–IQ correlation. Bors et al. demonstrated that accuracy at very long stimulus durations correlates with IQ, suggesting that low IQ participants sometimes perform poorly even on very easy trials. Such a finding suggests that these participants may perform the IT task inconsistently. Other studies of ECTs, have found that intra-individual variability (meaning consistence of performance for an individual, trial to trial), such as the standard deviation of reaction-time (RTSD), are often better predictors of intellectual performance than reaction-time means (Jensen, 1992). While Bors et al. did not report participants' standard deviations, the finding that low IQ participants fail on the easiest trials could result from lesser engagement in the task reflected in greater intra-individual variability.

An important consequence of intra-individual variability is that it tends to inflate mean values for many ECTs. When means are used to assess performance, those who perform inconsistently on ECTs will appear to perform poorly even if their best performances on some individual trials are very fast. A strong relationship between means and intra-individual variability complicates interpretation of the IQ–ECT correlations because it suggests plausible explanations involving third variables. For this reason it is critical to determine whether ECTs directly measure neural speed or other variables. Bors et al.'s findings suggest the possibility that performance on IT in part reflects attentional control. A growing body of literature on individual differences in working memory demonstrates that higher performing participants can more aptly allocate attention commensurate with instructions (e.g. Colflesh & Conway, 2007; Conway et al., 2001). For example, Conway et al. found that participants with higher working memory spans were less likely to hear their name in one ear when instructed to allocate attention to the other in a dichotic listening task. IT, like many attentional tasks, may in part reflect the ability to remain focused from trial to trial, and this ability should manifest as low intra-individual variability.

The aim of the following experiments is to test whether intra-individual variability in IT predicts IQ and to determine whether this variable reflects, at least in part, individual differences in attentional control. In Experiment 1 we test whether intra-individual variability accounts for the IT–IQ correlation by estimating IT with a stepwise procedure and computing the standard deviation of IT (ITSD). In Experiment 2 an auditory dual task is employed during estimation of IT to test whether high and low IQ participants differentially allocate attention.

1. Experiment 1

An alternative stimulus-selection procedure was developed for Experiment 1 that would maximize intra-individual variability. The procedure changed the SOA of the stimulus at every trial based on the accuracy of responses. Correct responses elicited briefer SOAs on subsequent trials and incorrect responses yielded longer SOAs.

1.1. Method

1.1.1. Participants

Participants were 77 Florida State University undergraduates receiving course credit for participation. All participants were at least 18 years old.

1.1.2. Materials

IT was estimated on a 19-inch CRT monitor with a refresh rate of 60 Hz, allowing SOAs approximating multiples of 17 ms. A l." by .75" pi-shaped stimulus was presented and participants attempted to determine which of its two parallel lines was shorter. The difference in the length of the lines occupied one-third the length of the stimulus. A fixation cross was displayed for 1 s in the center of the screen followed by the stimulus. A non-standard 100 ms backward mask (recommended by Simpson & Deary, 1997) immediately followed and participants had as much time as they desired to enter their response. Stimulus duration for each of 90 trials was determined by utilizing a one-up-one-down adaptive staircase procedure beginning with presentations of 102 ms. Correct responses resulted in a 17 ms. decrease in subsequent SOAs whereas incorrect responses resulted in a 17 ms. increase. For example, if a participant correctly answered the first four trials and missed the fifth and sixth, the SOAs on the first seven trials would be (in ms), 102, 85, 68, 51, 34, 51, 68. To prevent practice effects, training was limited to five trials at 102 ms.

1.1.3. Procedure

Participants were administered the short form of Set II of the Ravens Advanced Progressive Matrices (Bors & Stokes, 1998; Raven, 1965), which shares all the reliable variance with the original test. They were then situated at a comfortable distance in front of a computer monitor to estimate threshold IT.

1.2. Results

Threshold-IT was originally measured by determining which SOA at least 90% accuracy was achieved for each participant. At the suggestion of a reviewer a more conventional method was used in which threshold-IT was derived by

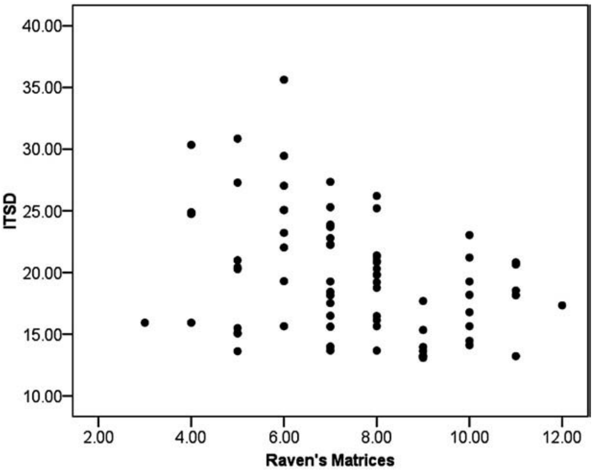

Fig. 1. Scatterplot of correlation between Raven's Matrices and ITSD in Experiment 1.

fitting a cubic function to percentage-correct at each SOA and solving for a criterion of 75%. The methods were highly correlated (r=.73), and the latter is used in the following analyses. ITSD was obtained by determining the duration of the SOA at which every trial had occurred and computing the standard deviation of these values for each participant. Two participants were eliminated from the analysis for failure to follow directions (they had essentially zero accuracy), and two others were eliminated for loss of data.

Similar to previous research, threshold-IT correlated with Raven's matrices, r (71)=−.25, p<.05, which is close to the uncorrected IQ–IT correlation reported in the meta-analysis by Grudnick and Kranzler (2001). ITSD correlated strongly with threshold-IT, r (71)=.65, p<.001, indicating that participants with greater intra-individual variability tended to have higher threshold inspection times. As illustrated in Fig. 1, ITSD correlated with Raven's matrices, r (71)=−.34, p<.05, indicating that greater intra-individual variability is associated with lower performance on this IQ test. Finally, a regression analysis demonstrated that the Raven–IQ relationship was no longer reliably predicted by threshold IT after adding ITSD, p>.05, indicating that ITSD fully accounts for the reliable IQ–IT variance.

1.3. Discussion

As predicted, the one-up-one-down stimulus-selection procedure yielded threshold-IT correlations with the Raven comparable to those in previous studies (cf. Grudnick and Kranzler, 2001). Moreover, ITSD correlated substantially with threshold-IT and the Raven. Regression analysis revealed that even in a relatively large sample of 73 subjects, threshold-IT did not predict scores on the Raven after ITSD was taken into account.

These findings demonstrate that participants performing well on the Raven also showed consistent performance on the IT task. However, these findings alone do not establish whether intra-individual variability in performance merely reflects perceptual processing speed and efficiency, individual differences in attentional control, or both. One possibility is that attentional control accounts for the results, either alone or as a mediator for perceptual speed. Assuming for example, that perceptual speed reflects general processing speed, then generally slower processing may lead to attentional distraction. In contrast, a pure perceptual speed theory makes differing predictions about how participants should perform at IT under dual task conditions. When performing another task simultaneously with IT, with instructions to attend primarily to the other task, low IQ participants should continue to perform worse at IT if IT directly reflects perceptual speed. If performance on IT is determined by perceptual speed, diverting attentional resources to another task should not prevent high IQ individuals from retaining their superiority. However, if IT reflects attentional control, high IQ participants will attend to the primary task better than lower IQ participants, resulting in their having fewer attentional resources to devote to the IT task relative to non-dual task situations. In other words, the high IQ individuals' primary cognitive advantage resides in their greater attentional control, not necessarily in their faster perceptual speed, and a secondary task will remove this advantage, primarily impairing the IT performance of high IQ individuals. The next experiment attempts to test between pure perceptual speed and attentional control theories by having participants perform an additional primary task simultaneously with the IT task.

2. Experiment 2

In Experiment 2 participants were presented with a dual task to establish whether IT primarily measures perceptual speed or attentional control. If the IT task primarily measures perceptual speed, lower IQ individuals should suffer greater performance deficits on the IT task and the standard IT–IQ correlation should be preserved. However, if IT primarily measures attentional resources, higher IQ individuals will suffer deficits in IT performance with the dual task present.

Egan and Deary, (1992) conducted a similar experiment examining the impact of dual task performance on strategy use. The results of the study supported the speed theory as dual task performance marginally increased the IT–IQ correlation. However, the additional task used in this study, a running-summation arithmetic task, is systematically related to IQ. Hence, given that higher IQ participants have superior arithmetic performance, the running-summation task is likely to require fewer attentional resources for high IQ individuals. The task was likely more difficult for the lower IQ participants, perhaps causing a greater cognitive load, resulting in greater deficits in IT. It is also possible that high IQ participants were less likely to emphasize the running-summation task as it was considered the secondary, rather than the primary task.

In Experiment 2 we employ a dual tasking paradigm in which the primary task is likely less related to IQ performance and in which we emphasize the primacy of this task to participants. Our hypothesis is that high IQ participants will attend more to the primary task leading to greater IT variability.

In the primary task subjects were instructed to verbalize the words of a recording played into a headset. This task was chosen because verbalizing pre-recorded words requires an auditory input and non-visual output modality and is unlikely to affect higher or lower IQ individuals differently, given that several studies have found no effect of concurrent verbalization on Raven performance (e.g., Russo, Johnson, & Stephens, 1989).

2.1. Method

2.1.1. Participants

Twenty-five additional undergraduates were recruited from the department of psychology participant pool at Florida State and received course credit for participating. All participants were at least 18 years old.

2.1.2. Materials

A recording was made of an experimenter reading from the instruction manual of a software application unfamiliar to participants for the primary task.

2.1.3. Procedure

Participants were outfitted with a headset and instructed to repeat everything they could hear. The first 30 s of the recording was played to familiarize participants with the task. Participants were then situated a comfortable distance from the computer monitor for the IT task. Instructions emphasized that repeating what they heard in the headset was their first priority and the IT task was secondary. The IT estimation procedure was identical to that outlined in Experiment 1 except that the recording for the primary task commenced after the second test trial. Once again participants were administered the Raven's after the IT task.

2.2. Results

Overall, the dual task proved effective at increasing the mean threshold-IT compared to Experiment 1. The threshold-IT of Experiment 1 ($M=40$ ms, SD=26 ms) was significantly lower than the threshold of Experiment 2 ($M=87$ ms, SD=38 ms) as revealed by an analysis of variance, $F(1, 96)=46.52$, $p<.001$. However, in Experiment 2, the correlation between threshold-IT and IQ was reversed, $r(23)=.41$, $p<.05$, as was the correlation between ITSD and Raven, $r(23)=.40$, $p<.05$, indicating that participants with higher Raven scores showed both higher threshold-ITs and more IT variability (shown in Fig. 2)—the opposite of the findings from Experiment 1. ITSD was again strongly correlated with threshold-IT, $r(23)=.68$, $p<.001$. Moreover, a regression analysis revealed that the relation between threshold-IT and Raven was no longer significant after accounting for ITSD, as in Experiment 1, $p>.05$. Intra-individual variability accounted for the shared IT–IQ variance.

These results indicate that higher IQ participants were more affected by the dual task, performing significantly worse on IT. An attentional control account of the findings would posit that this was due to higher IQ participants attending more to the primary task. Attentiveness to the primary verbal shadowing task was measured by mean response times (time to enter a response) on the IT task, as response time did not correlate with IQ in Experiment 1. Slower response times of higher IQ participants on the IT task support this inference. Indeed, Raven scores correlated with IT response times, $r(23)=.40$, $p<.05$, and IT response time also correlated with threshold-IT, $r(23)=.43$, $p<.05$, as well as ITSD, $r(23)=.46$, $p<.05$. Finally, a regression analysis revealed that correlations between ITSD and Raven, and threshold-IT and Raven, were no longer significant after accounting for IT response times, $p>.05$. Hence, higher IQ participants were expending more resources on the primary verbalization task, causing them to take longer during IT trials. Critical to our hypotheses, performance on the IT task was clearly related to management of attentional resources.

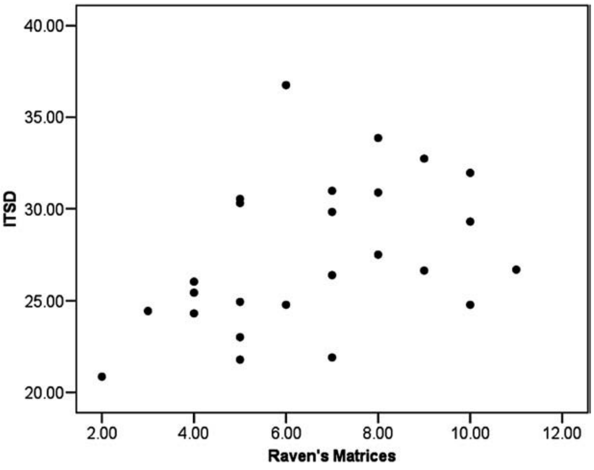

Fig. 2. Scatterplot of correlation between Raven's Matrices and ITSD in Experiment 2.

2.3. Discussion

These results are most consistent with attentional control influencing IT performance given that the primary task had a greater impact on higher IQ participants. We had not initially expected the effect to be strong enough to reverse the correlation, however, this finding is consistent with an attentional control explanation. The finding that higher IQ participants also had longer response times on IT trials with a dual task indicates that they were being more attentive to the primary verbalization task, which is inconsistent with a pure perceptual speed theory. Moreover, we again found threshold–IT and ITSD were highly correlated, mirroring Experiment 1. This may suggest that the same mechanism, namely attending more fully to the task, results in the superior IT performance of high IQ participants in the first experiment as well as their inferior IT performance in the second. It is unlikely that neural speed or efficiency could account for this finding without acknowledging attentional control as an important mediator. Faster processing should result in less interference from a dual task, and the IT–IQ correlation should have been preserved, rather than reversed. These results run counter to the findings of Egan and Deary, supporting our hypothesis that g-loaded dual tasks may disproportionately tax low IQ participants.

However, Experiment 2 cannot rule out the possibility that higher IQ participants may possess faster neural processing abilities; it does, however, suggest that the IT task primarily measures attentional control. These findings do not allow for dismissal of speed and efficiency theories but provide evidence that such theories cannot explain the IT–IQ correlation without acknowledging what is at least a mediating role for attentional control.

3. General discussion

Our results suggest that attentional control contributes strongly to the IT–IQ correlation. We argued that attentional control should manifest as task consistency and found that consistency, as measured by ITSD, accounted for the IT–IQ correlation in Experiment 1. A pure perceptual speed theory could have accounted for this finding, but Experiment 2 showed that a dual task interfered more with higher IQ participants' performance, resulting in a reversed IT–IQ correlation. These results are consistent with an attentional control theory for IT, and other findings suggesting that increased attentional load disproportionately impedes higher performing individuals (Rosen & Engle, 1997). It appears that those with higher cognitive ability are better able to allocate attentional resources and that this may lead to greater vigilance during performance of IT and possibly other cognitive tasks.

Importantly, our study does not show whether or not lower IQ participants could voluntarily allocate their attentional resources better and consequently lower their threshold-IT levels in the typical IT task. However, such an interpretation would be consistent with the finding that practice on IT attenuates the IT–IQ correlation to non-significance (Bors et al., 1999), as it would likely mean that practice on IT results in greater use of some resource (e.g. focusing more on the task) for lower performers. We suspect that this could potentially explain why some studies do not find a clear practice effect for IT (Irwin, 1984: Irwin's IQ scores were relatively high), as it would only occur when participants (particularly with lower IQ scores) reduce their variability. In this respect, the present study cannot address whether attentional control is primarily a limited capacity (e.g., working memory) or whether it is also determined in part by motivational factors.

Finally, it is possible that greater attentional control is caused by superior speed of neural processing in the brain. Faster processing may lead to quicker perception and better attentional control. However, our results, and those of Bors et al. (1999), suggest that IT is strongly influenced by downstream processes and is probably not a psychophysically pure metric of perceptual speed. The parsimony of claims that IT measures a more specific type of speed, (viz. perceptual speed; e.g., Deary, 1995; Egan & Deary, 1992) is compromised, but variants of these theories cannot be refuted by our data. Only a theoretical account at the neural level can precisely identify the mechanisms mediating individual differences in performance. At the cognitive level, however, attentional control provides the simplest explanation of the IT–IQ relationship.

Our findings highlight the role attentional control may play in the IT–IQ correlation, as we have attempted to incorporate findings from working memory and attention literature to investigate one ECT's relationship with IQ. Others have demonstrated that attentional control is related to higher-level cognitive performance (e.g. Colflesh & Conway, 2007; Conway et al., 2001), suggesting that this ability may underlie the relationship between simple tasks and IQ. It is unclear whether our findings generalize to other ECTs; however, our results emphasize the potential complexity of even the simplest cognitive tasks and challenge the existence of direct measurable relationships between neural speed and IQ.

Acknowledgements

We would like to thank Edward Cokely and Neil Charness for many helpful suggestions.

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