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Attempting to differentiate fast and slow intelligence: Using generalized item response trees to examine the role of speed on intelligence tests

Jack DiTrapani [a,*], Minjeong Jeon [a], Paul De Boeck [a], Ivailo Partchev [b]

[a] Department of Psychology, The Ohio State University, 1827 Neil Avenue, Columbus, OH 43221, United States
[b] Cito, Amsterdamseweg 13, 6814 CM Arnhem, Netherlands

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ABSTRACT

Past research has indicated that a person's speed on cognitive tasks is correlated with his or her intelligence (Sheppard & Vernon, 2007). This has influenced the belief that faster respondents on intelligence tests may be more intelligent than those who are slower. Within this context, previous research has employed a one-parameter item response tree model to intelligence test data and concluded that there are two unique test-taking processes: one process for fast responses, and one for slow responses (Partchev & De Boeck, 2012). This study asks similar questions, but instead uses a two-parameter item response tree model. This model allows the researcher to calculate separate sets of item parameters for when an item is answered quickly versus when it is answered slowly. This item response tree model is fit to 503 respondents to a matrix intelligence test and 726 respondents to a verbal test. Results show that each item has separate parameters for fast and slow responses. Furthermore, for both matrix and verbal tests, the item discrimination parameters are consistently higher for fast responses, suggesting that fast responses to an item may contain more information about the ability of the respondent than slow responses.

1. Introduction

A common topic within intelligence research is the interplay between a person's intelligence and the speed at which one completes mental tasks. The possible relationship between speed and power has been investigated and discussed for decades (e.g., Beck, 1933; Brand, 1981; Eysenck, 1967; Kelley, 1927). Many early theorists reasoned that speed and power are a part of a single latent trait, such as Spearman's *g* (Spearman, 1927). At least semblances of this notion have lasted to today, as speed is often thought of as an indicator of intelligence.

Numerous studies have been conducted on the relationship between IQ scores and mental speed. Many of these investigations look at the speed of participants on cognitive tasks independent of an intelligence test, not the response times of actual intelligence test items. These tasks are often denoted as Elementary Cognitive Tasks, or ECTs. ECTs are not identical to intelligence test stimuli, but are similar and rudimentary enough that it is postulated that they measure basic levels of cognitive ability. Because performance in many of these tasks is measured by speed of completion (e.g. reaction time tests), it is common to compute correlations between intelligence test scores (calculated from a measure independent of the ECTs) and speed levels on ECTs, and therefore attempt to make a link between intelligence scores and cognitive processing speed.

When these relationships are examined, ECT speed and intelligence scores are often positively correlated. This implies that there is a negative correlation between the response time and intelligence (since a higher response time means a lower speed). There is an abundance of research that suggests that the faster the mental processing speed of an individual, the higher the intelligence score of this person (Neubauer & Bucik, 1996; Sheppard & Vernon, 2007; Vernon, 1983). A similarly positive correlation has been found between intelligence scores and inspection time speed. Inspection time is a slightly different concept from reaction time, and is defined as "the quickness of the brain to react to external stimuli prior to any conscious thought." (Kranzler & Jensen, 1989). The distinction between these two types of reaction times is subtle, but meta-analyses have shown that speeds on each of these tasks are both positively related to a subject's measure of intelligence (Kranzler & Jensen, 1989; Sheppard & Vernon, 2007).

One possible interpretation of this evidence is that more intelligent minds are simply "faster" than others, leading to faster response times in elementary cognitive tasks. This has helped fuel the idea that mental speed and mental power are not separate entities but are in fact intertwined as related traits. However, this does not necessarily imply that faster responses on the intelligence test itself leads to better scores.

One result that has been found with these ECTs is the Worst Performance Rule, or WPR (Coyle, 2003). This phenomenon suggests that the slowest (or "worst") responses on ECTs for a given person tend to

* Corresponding author.
E-mail address: ditrapani.4@osu.edu (J. DiTrapani).

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predict that person's intelligence score significantly better than that person's average or fast responses, across many different conditions and tasks (Baumeister & Kellas, 1968; Larson & Alderton, 1990). Extending this framework to intelligence testing, it may follow that, much like the WPR, a respondent's slowest responses to an intelligence test may tell us the most about the intelligence of the respondent. If this were found to be the case, it may be evidence of a connection between intelligence tests and performance on an ECT, suggesting that ECT speed and intelligence test response speed may represent similar aspects of mental speed. Like most ECT studies, WPR analyses are done at the person level, meaning an individual's slowest responses are used. This paper uses an unconventional approach to investigate if the WPR can be found at the item level as well.

ECTs that measure working memory (Baddeley, 1986) have also been used to study the relationship between cognitive speed and a construct of ability. Scores on these working memory tasks have consistently been found to be positively correlated with mental processing speed (Waiter et al., 2009) as well as with intelligence scores (Gray, Chabris, & Braver, 2003; Troche & Rammsayer, 2009), providing a link relating cognitive speed with working memory. However, these studies still do not focus on the response times directly from the intelligence tests themselves. ECT studies provide evidence that those who process information quickly tend to perform better on intelligence tests, but they give us little information regarding the relationship between a respondent's ability and his or her speed on intelligence test items. In this paper, we will investigate responses and response speed directly from the intelligence items, which has not commonly been investigated in ECT and WPR research.

There have been attempts to examine responses and response times not from ECTs but from the actual intelligence items (Davison, Semmes, Huang, & Close, 2011; Van der Linden, 2009). The majority of this research is done on participants under time-pressured conditions; however, there have still been some attempts to look at response times on tests that do not have a time limit. Correlations between the speed of an individual and his or her intelligence scores on a freely-timed test have ranged from negative (Klein Entink, Kuhn, Hornke, & Fox, 2009), to nonexistent (Davison et al., 2011), to highly variable from one test to the next (Van der Linden, 2009).

1.1. Fast and slow: different processes?

In a situation where there is no time pressure, one can postulate several reasons why a response may be quick or slow. One possibility parallels the ECT studies: those with a higher level of intelligence are able to arrive at the correct response at a faster rate. However, one could easily make the counterargument that impatient or unfocused individuals will tend to make rash, quicker decisions, resulting in faster answers but lower scores of intelligence, the opposite result to the first speculation.

Among this confusion, one theory suggests that fast and slow responses may not be a result of faster cognitive speed or levels of impatience, but of the usage of different processes by the respondents. Items may be approached and answered using different strategies, or processes, and these processes may vary in the time it takes to complete them.

Take for an example the math problem shown in Fig. 1. There are potentially two distinct methods of approaching this question. A geometry student with much experience in the subject would immediately and automatically recognize that the answer is 135° (180° − 45°). This approach uses "automatic" processing (Shiffrin & Schneider, 1977), where the respondent quickly and intuitively recognizes how to solve the problem just by initially glancing at the situation. An inexperienced geometry student, or a more thorough one, may instead sequentially work his or her way down to the angle in question. This process uses "controlled" processing, and will tend to be slower. However, it is difficult to say which type of approach is more likely to get the question correct. Those who use automatic processing often get to an answer at a quicker rate and go through fewer mental steps that may result in a mental error, but are more vulnerable to "tricky" items that try to take advantage of a respondent's initial, knee-jerk reaction to seeing the item. A more patient respondent who uses a controlled approach will not fall victim to "trap" items, but may be more likely to make a calculation error, since there are more opportunities to do so. Therefore, we hypothesize that response speed is relevant not because it may show a direct measure of a person's cognitive processing speed, but because it signifies that a different process was used, which may affect how difficult the item is. In essence, the speed of a response may be an indicator of whether a respondent used an automatic or a controlled approach to the item, possibly changing the properties of that item. These ideas are posed and explored by Goldhammer et al. (2014).

Unlike the above example, items from an intelligence test would not realistically have such stark differences in automatic and controlled strategies. However, the logic is that an item can have subtle differences in how it can be approached, leading to differences in the item's parameters dependent on what type of strategy (fast or slow) is adopted. If a fast response is observed, then one could theorize that a more automatic process was used, which may alter the properties of that item (for example, the geometry problem could be more difficult if the automatic process is adopted). Therefore, the strategy that may have been used by the respondent is explicitly included in the data as "fast" or "slow," and is treated as an observed, discrete, and dichotomous variable.

This formulation provides another question: if a given item can have different sets of parameters, can individuals have different levels of abilities on each type of process as well? It is reasonable to think that respondents may have a higher relative ability on faster processes than on the slower responses. This situation would be particularly relevant for intelligence testing, as it would be problematic if a test was attempting to measure one latent ability of respondents (general intelligence), when in fact two separate variables (fast/automatic and slow/controlled intelligence) were being measured.

1.2. Prior research

Partchev and De Boeck (2012) proposed a branching item response model to investigate if respondents have a "fast" and "slow" intelligence. When this model was applied to intelligence data, the model was able to differentiate separate latent abilities for fast and slow responses, meaning each respondent had two different measured latent traits: one for fast responses, and one for slow. Unsurprisingly, these propensities were highly correlated for inductive reasoning data ($r = 0.879$ for verbal analogies, $r = 0.869$ for Raven-like matrix comprehension), meaning that although there were two separate abilities being measured, they were quite similar within a given person. This would suggest that respondents who tended to succeed when answering quickly would be more likely to also succeed when answering at a slower rate.

It was also shown for matrix questions that there was a significant negative correlation between a person's "speed tendency" and inductive intelligence ($r = -0.422$), implying that those who tend to take more time on matrix tasks receive better scores. The speed-ability relationship found here is notably in the opposite direction compared to the aforementioned correlations found in meta-analyses comparing different reaction time task speeds and IQ scores (Kranzler & Jensen, 1989; Sheppard & Vernon, 2007). This finding, which will be explored further in this present study, provides evidence that the positive relationship between reaction time speeds and intelligence scores may only be present when looking at ECT response times, and may not be applicable to response times taken directly from intelligence test responses.

Looking at item parameters yielded similar findings, as each item was discovered to have different difficulties depending on how quickly it was answered. The branching model used in this study is often denoted as an item response tree, or "IRTree" model (e.g., De Boeck & Partchev,