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The relationship of choice reaction time variability and intelligence: A meta-analysis☆

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ABSTRACT

Frequently the relationship of the variability of reaction times (RTSD) on elementary cognitive tasks and psychometric general intelligence (*g*) has been investigated. A typical finding is that stable reaction times (low RTSDs) on very basic choice reaction tasks are associated with high *g*. This meta-analysis quantifies the phenomenon by integrating 24 studies of 27 independent samples with a total of 3968 subjects using comparable, Hick-derived paradigms (Hick 0, 1, 2, 3 bit; odd-man-out). Special attention was given to the disattenuation of correlations for reliability artefacts. Random effect meta-analysis yielded small to moderate relationships between intelligence and reaction time variability, the pooled Pearson correlation ranging between −.18 (0 bit) and −.28 (2 bit). The relationship did not, however, prove consistently larger than the one between intelligence and reaction time, in contrast to earlier findings.

1. Introduction

The choice reaction time task (Hick, 1952; Hyman, 1953) is one of the most extensively studied tasks in experimental psychology. Median or mean reaction time (RT) is studied more often than reaction time variability (RTSD), typically calculated as the standard deviation of the reaction times. RT and RTSD are positively correlated: A statistical explanation of the positive correlation is that a high variability of reaction times on the same task will often lead to a higher mean or median, as the range of observed values increases with variability. While some researchers see little added benefit in investigations of RTSD (e.g. Roberts & Stankov, 1999), Jensen (2006) argues that RT and RTSD are two different basic chronometric variables. Also, there is evidence from factor analytic methods and structural equation modelling that they are not identical (Jensen, 1992; Rammsayer & Troche, 2010).

Frequently, intelligence and RT/RTSD have been found to correlate negatively in a large variety of populations, though correlations are most often in the range of −.30 to −.20. Faster reaction times and low RTSD are associated with higher intelligence (Deary, 2000). If RT is seen as a measure of information processing, then over the course of many years, a low RT or RTSD allows more to be learned which in turn leads to higher intelligence. A more biological explanation is that differences in RT or RTSD reflect noise in information processing due to errors in synaptic transmission (Eysenck, 1987).

Another psychophysical approach is oscillation theory (Jensen, 1982a). It is put forward that neurons switch between a refractory and an excitatory state, and an increase of the oscillation rate predicts improvements in psychometric intelligence (*g*) and reductions in RT and RTSD. Rammsayer and Brandler (2007) described the close relations of oscillation theory and the idea of an internal master clock (Surwillo, 1968). Beauducel and Brocke (1993) cautioned that oscillation theory might not be specific enough to be scientifically useful.

Longstreth's (1984) critique of Jensen's work already contained thoughtful examinations on attention as a confounding influence on the RT–*g* and RTSD–*g* relationships, likely through visual displacement effects. Attentional requirements have also been suspected by Carroll (1987) to be a decisive explaining factor for the correlation of RT/RTSD and g. There is also evidence in works of Carlson, Jensen, and Widaman (1983) as well as Carlson and Widaman (1987). Bors, MacLeod, and Forrin (1993) and Bates and Stough (1997) investigated spatial attention as a confounding factor by narrowing the area in which stimuli are presented, leading to reduced correlations of RT with *g* in the narrower conditions. Neubauer, Bauer, and Höller (1992) included the d2 test of attention (Brickenkamp, 1978) into their study of children aged 11–15 and found a correlation of the d2 number processed correctly score of −.34 with RT and −.42 with RTSD. These were larger than the correlations with Standard Progressive Matrices (−.14 and −.25 in an uncommon condition with feedback on performance in the Hick paradigm). In addition, attentional deficit disorder has been linked to an increased intraindividual variability of reaction time

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(Vaurio, Simmonds, & Mostofsky, 2009) and also the close links of attention and intelligence are well studied (Schweizer & Moosbrugger, 2004; Schweizer, Moosbrugger, & Goldhammer, 2005). Attention is hence at least a moderating factor of the RT/RTSD–*g* relationship.

1.1. The Hick paradigm in intelligence research

The relationship of RTSD and intelligence is typically investigated using an elementary cognitive task (ECT) to measure RTSD and is calculated from measurements of reaction times on several trials on the same ECT. In the context of this meta-analysis, the ECTs of interest are derivatives of the Hick paradigm. Roth (1964)[1] studied the Hick law using an apparatus that inspired a long line of research. Berkson and Baumeister (1967) were the first to study the relationship of RTSD and intelligence with a two group design.

Jensen proposed that the standard deviation of reaction time as a measure of variability of the reaction time is of equal importance as a measure of central tendency such as the median or mean. Jensen's implementation of the Hick paradigm (Jensen & Munro, 1979) used a device which became known as the "Jensen box", see Fig. 1. It is a reference point for the methodology of all primary studies in this meta-analysis.

The basic experimental condition is the simple (or 0 bit) condition, in which only one light (or more generally one stimulus) is used. The subject is instructed to react as quickly as possible when the light is switched on. The task increases in complexity, when the number of lights that can potentially be activated is increased, and typical numbers of choices include two, four and eight (corresponding to 1,2 and 3 bit in the sense of information theory and the Hick law). If a home key is used which the finger presses until the light is switched on, it is possible to separate the decision time (DT; the time until the finger is lifted from the home key) from the movement time (MT), the time it takes to reach the light or a corresponding button near the light. This is the case for the Roth (1964) device, the Jensen box, and some computerized implementations. Some researchers have argued that the correct measure of RT is in fact the DT (Jensen, 1982a; Roth, 1964).

The home key design and the interpretation of DT as RT stood not without criticism (Longstreth, 1984; Neubauer, 1991), as especially the interpretation of DT is difficult if subjects employ different strategies (lift finger as early as possible vs. lift finger when movement to button is fully coordinated). Neubauer (1991) and Neubauer et al. (1992) presented another implementation of the Hick paradigm in response to this and related points of criticism. Fingers rest on several buttons (up to four) without pressing them, so that DT and MT cannot be discerned. Thus the measured reaction time is a sum of DT and MT. Also, the stimuli are closer together to reduce retinal displacement effects. Deary, Der, and Ford (2001) employ a portable device (Cox, Huppert, & Whichelow, 1993) very similar to the Neubauer implementation. Fully computerized implementations that use computer monitors and keyboards (or other devices with buttons) have been employed as well (e.g. Larson, Merritt, & Williams, 1988; Rammsayer & Troche, 2010). Recently, Holm, Ullén, and Madison (2011) have used auditory instead of visual stimuli in the 1 bit condition.

Frearson and Eysenck (1986) extended the Hick paradigm in complexity by introducing the odd-man-out (OMO) task. Three stimuli are displayed, two of which are closer (spatially) to each other. The subject is to push the button of the odd-man-out as fast as possible. The original implementation on the Jensen box uses three out of the eight lights as stimuli and 24 patterns. Similar to the Hick paradigm, the OMO task has been computerized with different stimuli (e.g., Danthiir, Wilhelm, & Roberts, 2012; Diascro & Brody, 1994).

[1] Research on the relationship of intelligence and reaction times on simple tasks before 1964 is reviewed by Jensen (1982b).

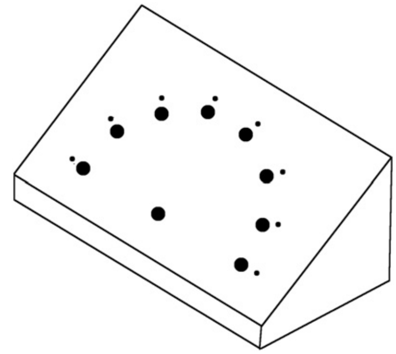

Fig. 1. Jensen box. Small circles indicate lights, large circles are buttons. The home key is 6 in. away from each response button.

1.2. Reliability of the Hick and OMO paradigm

As RTSD is a less reliable measure than central measures (Jensen, 1987), corrections for reliability have to be taken into account when discussing correlations between RTSD and other variables. Since the attenuation of the correlation increases as the reliability decreases, it is especially important for our investigation of the claim that the correlation of RTSD with *g* is larger than the RT–*g* correlation. Correcting correlations has also been frequently stressed in a meta-analytical context (Hunter & Schmidt, 2004).

1.3. Intelligence tests

Culture free matrix test, such as *Raven's progressive matrices* have been used predominantly, but not exclusively, to study the relationship of intelligence and RT/RTSD. Matrix tests are often said to be measures of the so-called factor *g*, or general factor of intelligence. Other "culture free" tests such as *Cattell's culture fair intelligence test* load heavily on this factor as well, and the same holds true for many intelligence test batteries. We will abbreviate the performance on matrix tests or highly correlated measures as *g* throughout the paper and prefer them as indicators of intelligence, but we take an agnostic stance to what *g* really is. From the perspective of current theories of intelligence (e.g. McGrew, 2005), this meta-analysis' preference of such measures might seem restrictive, but was necessary to arrive at a comparable set of studies.

1.4. Research aims

The purpose of this meta-analysis is twofold: to examine the relationship between RTSD and intelligence, and secondly, to see if the RTSD–intelligence relationship is indeed larger than the relationship between simple or choice reaction time and intelligence. Jensen (1987, 1992) supplied evidence for the latter claim, mostly using his own research. Reviewing more than 30 studies with more than 1400 subjects, he concluded that RTSD "generally has a larger negative correlation with psychometric *g*" (Jensen, 1992). This paper was frequently cited, especially in review articles (Coyle, 2003; Miller & Ulrich, 2013; Reed, 1998; van Ravenzwaaij, Brown, & Wagenmakers, 2011).

Sheppard and Vernon (2008) produced a large meta-analysis on intelligence and reaction time but did not include data on reaction time variability. To the best of our knowledge, no meta-analysis of the RTSD–intelligence relationship exists. As two decades had passed since Jensen's review, we expected that newer studies would complement the existing research.

A secondary aim of this meta-analysis was to gather information on the reliability of the Hick and OMO paradigms in the papers included in this meta-analysis. In addition, we determined split-half reliabilities for the Hick-derived paradigms from a sample of 65 subjects with a