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Performance on temporal information processing as an index of general intelligence

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Abstract

The relation between general intelligence (psychometric *g*) and temporal resolution capacity of the central nervous system was examined by assessing performance on eight different temporal tasks in a sample of 100 participants. Correlational and principal component analyses suggested a unitary timing mechanism, referred to as temporal *g*. Performance on single temporal tasks and individual factor scores on temporal *g* were substantially correlated with factor scores on psychometric *g*. Additional stepwise multiple regression analysis and commonality analysis showed that performance on temporal information processing provides a more valid predictor of psychometric *g* than traditional reaction time measures derived from the Hick paradigm. Findings suggest that temporal resolution capacity of the brain as assessed with psychophysical temporal tasks reflects aspects of neural efficiency associated with general intelligence.

Keywords: General intelligence; Timing performance; Reaction time; Neural efficiency

By use of cognitive information processing models and methods, our understanding of individual differences in mental ability has been improved considerably over the past three decades. A major experimental approach to elucidate basic cognitive mechanisms underlying general intelligence (psychometric *g*) originated from ideas of Galton (1883, 1908) and Spearman (1904, 1927). This approach is based on the attempt to relate psychometric *g* to speed of information processing (Brody, 1992; Jensen, 1987). Within this conceptual framework, a large number of studies provided evidence indicating a relation between levels of psychometric *g* and certain parameters of reaction time (RT) derived from *Hick's law*. Hick (1952) postulated a linear relationship between the amount of information measured in *bits* and a participant's RT. More specifically, *Hick's law* states a linear increase in RT with the binary logarithm ($\log_2$) of the number (n) of equally likely response alternatives in a visual RT task. This relationship can be expressed as $RT = a + b \log_2 n$ where a is the intercept and b is the slope constant. While the intercept a is usually interpreted as representing an estimate of the time required for sensorimotor processes such as stimulus identification and response execution, the slope b is considered an estimate of the time required for the cognitive processes of stimulus evaluation and response selection (Jensen, 1987).

In 1964, the German psychologist Erwin Roth provided first evidence for the assumption that the slope b of the Hick regression line should negatively correlate with

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psychometric intelligence since high intelligent individuals should need less time than low intelligent individuals to process one bit of information. In a study with 58 participants, Roth (1964) found a correlation of −0.39 between slope constant and a psychometric measure of general intelligence. This was the starting point for a large number of studies relating parameters obtained with the Hick task, such as median RT and individual variation in RT per bit level, the intercept *a* or the slope *b* of the regression line, to psychometric intelligence (for a review, see Jensen, 1987, 1998a). Various efforts to link these parameters, as indicators of speed of information processing, to psychometric intelligence showed rather inconsistent results. Nevertheless, several reviews arrived at the conclusion that uncorrected correlations of these mental speed measures and psychometric *g* average somewhere between 0.20 and 0.30 (e.g., Brody, 1992; Jensen, 1987, 1998a; Neubauer, Riemann, Mayer, & Angleitner, 1997).

Proceeding from the assumption that RT measures provide an index of the speed and efficiency with which the central nervous system processes elementary information, Jensen put forward the idea that the same basic characteristics of brain functioning determine both performance on the Hick task and level of psychometric *g*. According to Jensen's (1980, 1982) model of neuronal oscillations, individual differences in RT and psychometric *g* are considered a function of the rate of oscillation between a refractory and an excitatory state of the neuron. The speed of transmission of neurally encoded information is assumed to be faster and more efficient at a higher rate of neuronal oscillations. This is because with a higher rate of oscillation it will take less time for a neuron to enter the excitatory phase of its cycle when a stimulus is presented during the refractory phase than when oscillations are slow. As a consequence, individuals with a faster oscillation rate are expected to perform better on the Hick paradigm as well as on psychometric intelligence tests. Although the neuronal oscillation model provides a central feature of the relationship between Hick parameters and psychometric *g*, there is little empirical evidence in favor of this model (Brody, 1992).

The notion of an internal master clock represents an alternative metaphor to account for the relationship between efficiency and speed of information processing and psychometric *g*. The concept of a hypothetical master clock has been introduced by Surwillo (1968) to account for age-related cognitive impairment and general slowing. He proposed an internal clock mechanism in the central nervous system for coordination of different neural activities. More recently, Burle and Bonnet (1997, 1999) provided additional converging experimental evidence for the existence of some kind of master clock in the human information processing system.

Surwillo's (1968) basic idea can be transferred easily to the explanation of the relationship between speed of information processing and psychometric *g*. If we assume that the hypothesized internal master clock of individual A works, for example, at half the clock rate as the one of individual B, then A does not only need twice as long as B to perform a specific sequence of mental operations, but also the occurrence probability of interfering incidents will be increased. This should lead to lower performance on both the Hick task and tests for psychometric assessment of intelligence in individual A compared to B.

However, in order for the internal master clock interpretation to receive serious consideration, it must be demonstrated that some measure of clock rate reliably differentiates between individuals of low and high psychometric *g*. One of the most direct measures of internal clock rate represents temporal resolution capacity as indicated by timing accuracy. A large number of models of temporal information processing (e.g., Creelman, 1962; Gibbon, 1991; Rammsayer & Ulrich, 2001; Treisman, Faulkner, Naish, & Brogan, 1990; for a review, see Grondin, 2001) is based on the central assumption of neural oscillations as a major determinant of timing performance. According to this account, the higher the frequency of the neural oscillations the finer the temporal resolution of the internal clock will be, which is equivalent to greater timing accuracy. Furthermore, temporal resolution of the brain, as reflected by performance on genuine temporal tasks, can be considered largely independent of factors unrelated to temporal information processing, such as nontemporal cognitive operations or motor responses. Therefore, measures of timing accuracy appear to be a valid and sensitive behavioral indicator of internal clock speed.

Within the framework of human temporal information processing, the idea of different elementary time experiences such as interval timing, rhythm perception, temporal-order judgment, or simultaneity and successiveness has been put forward by several authors (Block, 1990; Fraisse, 1984; Friedman, 1990; Pöppel, 1978). Although the notion of elementary time experiences has been accompanied by the assumption of distinct timing mechanisms, a major controversy in the field of human timing refers to the question of whether psychological time represents a unitary concept or consists of distinct elementary temporal experiences. While the latter view implies different mechanisms underlying specific temporal experiences, a unitary concept of temporal processing would be consistent with the general idea that