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The influence of temporal resolution power and working memory capacity on psychometric intelligence

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ABSTRACT

According to the temporal resolution power (TRP) hypothesis, higher TRP as reflected by better performance on psychophysical timing tasks accounts for faster speed of information processing and increased efficiency of information processing leading to better performance on tests of psychometric intelligence. An alternative explanation of individual differences in psychometric intelligence highlights individual differences in working memory (WM) capacity which has been found to be closely associated with psychometric intelligence. A latent variable approach was applied on the data of 200 participants ranging in age from 18 to 30 years and spanning a large range of levels of psychometric intelligence. Functional relationships were examined among TRP, WM capacity, as well as reasoning and speed of processing as two important aspects of psychometric intelligence. As predicted by the TRP hypothesis, the relation between TRP and psychometric intelligence was mediated by WM capacity supporting the view that higher TRP leads to better coordinated mental operations which, in turn, result in higher psychometric intelligence. The results are discussed against the background that WM capacity and psychometric reasoning are hardly dissociable from each other and that the specific factors limiting WM capacity and accounting for the mediation effect need to be identified in future research.

1. Introduction

The oscillation rate of neuronal excitatory and refractory periods has been suggested to determine speed of information processing because information can be processed faster when the oscillation rate is high (Jensen, 1982, 2006). For example, if a stimulus is presented during the refractory state of a neuron or a group of neurons, it can be processed faster when the refractory period is short, i.e. the oscillation rate is high. In addition, less time required for performing a specific sequence of mental operations will decrease the occurrence probability of interfering incidents (cf., Lindenberger, Mayr, & Kliegl, 1993; Rammsayer & Brandler, 2002; Salthouse, 1991). Eventually, this should lead to higher efficiency of information processing as, for instance, indicated by higher speed and/or lower error rates in elementary cognitive tasks (ECTs) as well as in tests for psychometric assessment of intelligence (cf., Jensen, 1998).

The temporal resolution power (TRP) hypothesis of psychometric intelligence, introduced by Rammsayer and Brandler (2002), posits that frequency of neural oscillations can be indexed by performance on psychophysical timing tasks such as *duration discrimination tasks*, *temporal generalization tasks* or *temporal-order judgment tasks*. In duration discrimination tasks, duration differences between two stimuli have to be identified while in temporal generalization tasks, a standard duration has to be recognized within a series of standard and nonstandard duration. Temporal-order judgment refers to the question of how much time must intervene between the onsets of two different stimuli so that their order can be perceived correctly. All these psychophysical timing tasks have in common that they assess the accuracy with which small temporal differences can be perceived. Numerous psychophysical models of time

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perception focus on neural oscillations to explain human timing performance (e.g., Creelman, 1962; Gibbon, 1991; Rammsayer & Ulrich, 2001; Treisman, Faulkner, Naish, & Brogan, 1990; for a review see Grondin, 2001). These so-called pacemaker-accumulator models are based on the general assumption that a neural pacemaker generates pulses, and the number of pulses during a physical time interval is recorded by the accumulator. Thus, the number of pulses, counted during a given time interval, is the internal representation of this interval. Neural oscillations in the brain are proposed to be functionally equivalent to these pulses: The frequency of the pulses corresponds with TRP of the central nervous system and, hence, with timing accuracy.

Proceeding from the assumption that psychophysical timing tasks assessing temporal accuracy and timing sensitivity represent the most direct behavioral measures of TRP, several subsequent studies reported that higher TRP was associated with higher levels of psychometric intelligence (Helmbold & Rammsayer, 2006; Helmbold, Troche, & Rammsayer, 2006, 2007; Rammsayer & Brandler, 2007). In these studies, correlations between compound measures of psychometric intelligence and timing performance ranged from $r = .47$ to $r = .67$. These findings clearly indicate that TRP may reflect a basic brain mechanism involved in psychometric intelligence. Support for this view can also be derived from the finding that the relation between temporal information processing and psychometric intelligence is also observable at a very early, pre-attentive level of processing as indicated by the mismatch negativity in the electroencephalography (Troche, Houlihan, Stelmack, & Rammsayer, 2009).

The TRP account of psychometric intelligence is consistent with two major approaches of experimental research on intelligence: the mental speed approach (e.g., Sheppard & Vernon, 2008) and the working memory (WM) approach (e.g., Ackerman, Beier, & Boyle, 2005). Within the mental speed approach, higher TRP leads to a higher *speed of information processing* as measured with ECTs and, therefore, to better psychometric intelligence. On the other hand, higher TRP might also account for more efficient *coordination of mental operations* and, thus, increased WM capacity, which also contributes to better psychometric intelligence.

Several studies (e.g., Helmbold et al., 2007; Rammsayer & Brandler, 2007) investigated the first approach by employing a battery of psychometric intelligence scales, several psychophysical timing tasks, and mental speed measures derived from the Hick paradigm. The Hick paradigm is one of the most frequently used ECTs to assess the relation between speed of information processing and psychometric intelligence (for reviews see Deary, 2000; Jensen, 1998; Neubauer, 1997). Both speed of information processing and performance on timing tasks were highly related to psychometric intelligence. Moreover, the correlation between speed of information processing and psychometric intelligence could be explained almost completely by TRP.

In the studies of Helmbold et al. (2007) and Rammsayer and Brandler (2007), TRP accounted for a substantially larger portion of overall variability in psychometric intelligence than speed of information processing. This finding points to the conclusion that additional mechanisms are involved in the relation between TRP and psychometric intelligence. In accordance with the second implicit assumption of the TRP hypothesis, the relation between TRP and psychometric intelligence may be also effectively mediated by the quality of coordination of mental operations. Temporal coordination of mental operations should be most salient if information processing is subject to so-called bottlenecks of information processing which reflect limited resources on a particular level of processing. WM capacity represents one of the most important cognitive processes with limited resources. Although there are several divergent conceptions of WM (for a review see Miyake & Shah, 1999a), the most common feature of WM refers to the maintenance of information and concurrent processing of the maintained information (e.g., Baddeley, 1986; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Engle, Kane, & Tuholski, 1999; Oberauer, Süß, Wilhelm, & Wittmann, 2003). With increasing amounts of information to be stored and enhanced complexity of information processing, the limitations of WM capacity become obvious.

Previous studies showed that WM capacity was reliably related to psychometric intelligence (e.g., Colom et al., 2008; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Kyllonen & Christal, 1990; Martens & Johnson, 2009; Martínez & Colom, 2009; Schweizer & Moosbrugger, 2004). High correlations between WM capacity and fluid intelligence led some researchers to suggest that WM and the general factor of psychometric intelligence (*g*) are virtually identical (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kyllonen, 1996; Kyllonen & Christal, 1990). On the other hand, meta-analytical results rather suggest both constructs to be strongly related but clearly dissociable from each other (Ackerman et al., 2005). Nevertheless, WM capacity seems to play a crucial role in solving complex tasks that are used in scales assessing reasoning ability as an important aspect of psychometric intelligence (Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002).

In the present study, we investigated the interplay among TRP, WM capacity, and psychometric intelligence using structural equation modeling. Three TRP tasks and three WM tasks had been employed to establish latent variables for "TRP" and "WM capacity". As this is the first study on the interplay among TRP, WM capacity, and psychometric intelligence, WM capacity was assessed as a broad factor instead of multiple subsidiary factors to receive a first impression of the functional interactions among these three constructs. Psychometric intelligence was assessed by twelve subtests of the Berlin Intelligence Structure (BIS) test (Jäger, Süß, & Beauducel, 1997) to obtain measures of reasoning and speed of information processing as two important aspects of psychometric intelligence (Jäger, 1984). The separation of reasoning and speed of information processing should provide a more detailed picture on the functional relationship between WM capacity and TRP and their influence on psychometric intelligence. It should be noted that the speed component within the BIS model is related, but not identical to speed of information processing as assessed with ECTs (Neubauer & Bucik, 1996). BIS-Speed clearly represents an aspect of psychometric intelligence and, therefore, can be considered a criterion variable rather than a variable underlying psychometric intelligence. Henceforth, the term *BIS-Speed* refers to the BIS component, whereas *speed of information processing* refers to the more general construct of mental speed as it is