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Speeded testing in the assessment of intelligence gives rise to a speed factor

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ABSTRACT

This paper reports an investigation of whether data on intelligence obtained by speeded testing have to be represented in confirmatory factor analysis (CFA) by an additional factor besides the ability factor, and whether the additional factor can be identified as a speed factor. The paper further examined whether the hypothesized speed factor influences the relationship between intelligence and working memory. Two independent datasets including data obtained by speeded intelligence testing, measures of processing speed and of working memory were investigated by means of CFA. A hybrid bifactor model was employed to represent the hypothesized speed and the ability factor of the intelligence data. Whereas the factor loadings for representing ability were set free for estimation, the factor loadings for representing speed were constrained according to theory-based expectations. The results showed that a speed factor is necessary for achieving a good fit to the data with speeded testing. The convergent validity of the speed factor was shown by data on measures of processing speed. Furthermore, it turned out that the consideration of the latent speed factor led to a decrease of the correlation between intelligence and working memory. These results suggest that speeded testing influences the assessment of intelligence and may also bias empirical findings regarding the relationships between intelligence and other constructs.

1. Introduction

Recently, it was demonstrated that speededness in the assessment of intelligence contributes to the relationship between intelligence and working memory (Chuderski, 2013, 2015). Specifically, Chuderski's work indicated that working memory and intelligence were virtually indistinguishable when highly speeded intelligence measures were administered. Increasing the testing time of an intelligence measure substantially decreased the relationship between working memory and intelligence. Although this demonstration has not been undisputed (e.g., Colom et al., 2015), the comprehensiveness obvious in the combination of meta-analysis of empirical studies and the large sample size of the original work suggests that the addressed issue and the results deserve further consideration. Speededness appears to be an old issue of assessment research (see Gulliksen, 1950) that seems to have gradually lost importance. It is probably because correlations as indicators of convergent validity are normally not affected in such way by speededness that there is a change from significant to insignificant. Instead it appears to be only a matter of the magnitude of correlation. Furthermore, it is not likely that the fit of confirmatory factor analysis (CFA) models for investigating the construct validity (see Byrne, 2016) is influenced to a high degree by speededness. Nevertheless, it appears to be an important issue since nowadays most reasoning tests used as measures of fluid intelligence are administered with a time limit (Wilhelm & Schultze, 2002). If the time constraint leads to a reduction of the number of items attempted by all participants to $< 90\%$, the test is considered as speeded (Nunnally & Bernstein, 1994).

1.1. Speed as source of the relationship between intelligence and working memory

At first view and without knowledge of previous research into the cognitive basis of intelligence, a contribution of speed to higher mental ability appears not conclusive since the characteristics of the difficult intelligence problems suggest that a large capacity and specific processing strategies may be more important than speed. Furthermore, in attempts to simulate the completion of intelligence test items by Carpenter, Just, and Shell (1990), it is obvious that it is very characteristic for items of fluid intelligence tests that participants must perform a long sequence of actions before the final result is reached.

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However, Salthouse (1996) and Jensen (1998) point out that in such a situation processing speed may be of importance since it is instrumental in overcoming the limitations to the maintenance of intermediary results. Empirical evidence based on young adults does indicate that speed accounts for unique variance in fluid intelligence (Redick, Unsworth, Kelly, & Engle, 2012). If there is a time limit to completing the test, this limit may even increase the impact of individual differences in processing speed on performance because there may not be sufficient time for a retrial or for finding a way to overcome obstacles that prevent reaching the final solution. This consequence of the time limit can be suspected as a source of the observation that mental speed correlates higher with a speeded measure of reasoning than with an unspeeded one (Wilhelm & Schultze, 2002). The limit to testing time is especially effective in combination with complex items because of the increased probability of failure. This argument is in line with the observation that increased complexity is associated with increased correlations with speed (Roberts & Stankov, 1999). Since Salthouse and Jensen's reasoning applies to both fluid intelligence test items and many working memory tasks, it may provide a theoretical justification for Chuderski's (2013) results.

Besides the well-known argument by Salthouse (1996) and Jensen (1998), there are even more explanations that can be considered in favour of speed as a source of the relationship between intelligence and working memory. First, there is the argument that shared method variance is the source of the relationship. Shared method variance is created by time limits for all the involved measures. If there are time limits to measures of intelligence and of working memory, in each case the slow participants' performance scores stay quite away from what would be reached without the time limit whereas the fast participants' performance scores are close to what is possible for them. This means that similar rank orders are achieved in the measures of intelligence and working memory if there are time limits. This explanation is supported by the observation that the unspeeded administration of measures leads to smaller correlation coefficients of such measures than the speeded administration (Wilhelm & Schultze, 2002).

Another explanation highlights the influence of executive control as a major ingredient of working memory on mental information processing (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001). It is argued that the control of mental activity with respect to the task goal is a major function of executive control. It is necessary to assure that the processing of information smoothly switches from step to step in the direction of the task goal and to avoid deviation in the direction of alternative goals. Consequently, tight executive control can be expected to lead to a short processing time whereas lack in executive control prolongs the processing time. Executive control is not only necessary for completing cognitive tasks, it also plays a crucial role in completing intelligence test items (Miyake & Friedman, 2012; Ren, Schweizer, & Xu, 2013). This explanation is in accord with the worst-performance rule which suggests that slower participants may experience attention lapses during a cognitive task and thus need more processing time (Coyle, 2003; Fernandez, Fagot, Dirk, & De Ribaupierre, 2014).

1.2. The consequences of speeded testing for validity

A major criterion for the quality of a measure is validity. A measure is considered as valid if it represents the construct that it is expected to represent. This implies the expectation that data collected by means of this measure capture the construct of interest. The statistical models applied in validity investigations usually include parameters reflecting the construct but neglect speed. This practice led proponents of the major test theories to express concerns regarding the influence of speed on measurement because basic assumptions of measurement no longer hold (Hambleton & Swaminathan, 1985; Lu & Sireci, 2007). There are also attempts to prevent speededness from influencing the outcome of achievement testing (e.g. van der Linden, 2011).

On the other hand, there is the position that in the achievement area nowadays efficiency is more important than performance and may be preferred (Wilhelm & Schultze, 2002). Efficiency is usually defined as the ratio of performance and the time needed for completing a task. This definition is reflected by using a specified time frame for performance testing that means speeded testing. However, taking this position may require the establishment of a new definition or type of validity that reflects the needs of modern times to a larger degree than the available definition.

1.3. Models for the detection of the speed factor

A consequence of speeded testing is that not all participants are able to complete each item of a sequence of p items. The slowest participants attempt the smallest number of items n, assuming that there are p ($n < p$) items. The performance in completing these items can be assumed to be due to the ability that is measured by the test. The performance as the probability of a correct response P (X_i is correct) ($i = 1$, $2\ldots n$) solely depends on ability τ as source of individual differences besides characteristics of the items that, however, do not play a role in confirmatory factor analysis and are usually omitted:

$$\mathrm{P}\,(X_i \text{ is correct}) = \mathrm{P}\,(X_i \text{ is correct} \mid \tau)$$

It can be formalized by using an equation of a simple linear model of measurement that includes a true component τ for representing the ability and the error component ε (see Graham, 2006):

$$X_j = \tau + \varepsilon$$

If this model of measurement is transformed into the congeneric model of measurement (Jöreskog, 1971), it provides the basis for a CFA model with one factor representing the data.

In contrast, the item $n + 1$ is attempted by a smaller number of participants and the number of participants attempting item $n + 2$ is even smaller than the previous number, and so on. Compiling the frequencies of the attempted $n + 1$th to pth items gives a frequency distribution that is usually characterized by a steady decrease. The performance according to these items can no more be described by the true component τ and the error component ε alone. A further parameter reflecting the effect of speed on performance needs to be considered. In this paper, the influence of speed is considered by distinguishing between τ_{ability} and τ_{speed} so that performance as the probability of a correct response P (X_i is correct) ($I = n + 1, 2\ldots p$) needs to be written as:

$$\mathrm{P}\,(X_i \text{ is correct}) = \mathrm{P}\,(X_i \text{ is correct} \mid \tau_{\text{ability}}, \tau_{\text{speed}})$$

Furthermore, it is assumed that τ_{ability} and τ_{speed} are independent sources of variance that provide the basis for a CFA model with two factors.

Since data obtained by speeded testing suggest the presence of two different true components, the bifactor model (Canivez, 2016) needs to be selected for the investigation of these data instead of the simple congeneric model. The bifactor model includes a general factor with factor loadings of all items and a specific factor with factor loadings of some items only. In the ordinary bifactor model all factor loadings are estimated. This feature can be a disadvantage for representing the speed effect. The estimation of the factor loadings simply seeks to maximize the explained variance but does not necessarily reflect the assumed sources of variance. In order to achieve the representation of speed that reflects the assumed increasing share of the variance, the constraint of the sizes of the factor loadings is necessary. Such a representation of the speed factor was already proposed and found appropriate for reasoning data (Schweizer & Ren, 2013). It follows the logistic function. The size of the factor loading λ_i ($i = 1\ldots p$) is defined as follows:

$$\lambda_i = \frac{e^{i-k}}{1 + e^{i-k}}$$