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Individual differences in working memory capacity explain the relationship between general discrimination ability and psychometric intelligence

Stefan J. Troche *, Felicitas L. Wagner, Annik E. Voelke, Claudia M. Roebers, Thomas H. Rammsayer

Department of Psychology, University of Bern, Bern, Switzerland
Center for Cognition, Learning, and Memory, University of Bern, Bern, Switzerland

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ABSTRACT

The close association between psychometric intelligence and general discrimination ability (GDA), conceptualized as latent variable derived from performance on different sensory discrimination tasks, is empirically well-established but theoretically widely unclear. The present study contrasted two alternative explanations for this association. The first explanation is based on what Spearman (1904) referred to as a *central function* underlying this relationship in the sense of the *g* factor of intelligence and becoming most evident in GDA. In this case, correlations between different aspects of cognitive abilities, such as working memory (WM) capacity, and psychometric intelligence should be mediated by GDA if their correlation is caused by *g*. Alternatively, the second explanation for the relationship between psychometric intelligence and GDA proceeds from fMRI studies which emphasize the role of WM functioning for sensory discrimination. Given the well-known relationship between WM and psychometric intelligence, the relationship between GDA and psychometric intelligence might be attributed to WM. The present study investigated these two alternative explanations at the level of latent variables. In 197 young adults, a model in which WM mediated the relationship between GDA and psychometric intelligence described the data better than a model in which GDA mediated the relationship between WM and psychometric intelligence. Moreover, GDA failed to explain portions of variance of psychometric intelligence above and beyond WM. These findings clearly support the view that the association between psychometric intelligence and GDA must be understood in terms of WM functioning.

1. Introduction

When Spearman (1904) introduced the idea of a general factor of intelligence (*g*), he also reported an almost perfect correlational relationship between *g* and another factor derived from performances on weight, hue, and pitch discrimination tasks referred to as general discrimination ability (GDA). More recent studies have also demonstrated a reliable relationship between intelligence and sensory discrimination for different modalities. For example, in the auditory modality, duration (Helmbold, Troche, & Rammsayer, 2006), pitch (Raz, Willerman, & Yama, 1987; Voelke, Troche, Wagner, Rammsayer, & Roebers, 2013), and loudness discrimination were associated with intelligence (Troche & Rammsayer, 2009b). In the visual modality, color (Acton & Schroeder, 2001), line length (Meyer, Hagmann-von Arx, Lemola, & Grob, 2010), and duration discrimination (Haldemann, Stauffer, Troche, & Rammsayer, 2011, 2012) and, in the tactile modality, texture and shape discrimination were found to be correlated with intelligence (Stankov, Seizova-Cajić, & Roberts, 2001). In most of these

* Corresponding author at: Department of Psychology, University of Bern, Fabrikstr. 8, CH-3012 Bern, Switzerland. Tel.: +41 31 631 40 33.
E-mail address: stefan.troche@psy.unibe.ch (S.J. Troche).

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studies, measures from single discrimination tasks correlated only modestly with intelligence. However, when latent variables were derived from multiple sensory discrimination measures, correlations between psychometric intelligence and these latent variables, reflecting GDA, ranged between $r = .61$ and $r = .95$ (Deary, Bell, Bell, Campbell, & Fazal, 2004; Meyer et al., 2010; Troche & Rammsayer, 2009b). This indicates that task specific and error variance has to be removed to reveal the close relation between GDA and intelligence. Furthermore, it seems as if unspecific, amodal aspects of the discrimination process common to different kinds of sensory discrimination are the central features associated with psychometric intelligence (cf., Deary, 1994; Deary et al., 2004).

Even more than a century after Spearman's pioneering finding, the processes underlying the association between GDA and psychometric intelligence are still widely unknown. Spearman (1904) assumed a central function to underlie this association and "that this central Function, whatever it may be, is hardly anywhere more prominent than in the simple act of discriminating two nearly identical tones" (p. 174). More recently, different properties of the brain have been proposed to represent the neural processes underlying *g* in the sense of Spearman's central function such as neural plasticity (Garlick, 2002), neural pruning (Haier, 1993), or brain myelination (Miller, 1994). These brain processes theoretically explain why individuals who are better in one domain of abilities are also better in other domains. Although empirical evidence in favor of one of these brain processes is still missing it becomes clear that Spearman's idea of a central or fundamental function underlying *g* is still prevalent in the field of intelligence research (Nisbett et al., 2012). If it is true that there is a fundamental function accounting for the intercorrelations between different abilities and, hence, for the *g* factor and that this fundamental function can be most adequately assessed in terms of GDA, then it can be hypothesized that correlations between cognitive abilities and psychometric intelligence are mediated by GDA. Against the background of this rationale, it is surprising that, to date, there are almost no studies on possible mediating effects of GDA on the association between aspects of cognitive processing and psychometric intelligence.

An alternative explanation for the association between GDA and psychometric intelligence can be derived from insights into the sensory discrimination process obtained by functional magnetic resonance imaging (fMRI) studies. Nenadic et al. (2003) found the auditory cortex, prefrontal cortex, anterior cingulate cortex, and the striatum to be involved in auditory duration and pitch discrimination. Ferrandez et al. (2000) identified neural networks underlying visual duration and intensity discrimination which comprise the dorsolateral prefrontal cortex (DLPFC), anterior insula, inferior parietal area, striatum, parts of the cerebellum, mesencephalon, thalamus, the anterior cingulate as well as frontal and temporal areas. Also Livesey, Wall, and Smith (2010) reported activity in the DLPFC, the supplementary motor area, the inferior parietal area, the striatum, and the cerebellum during visual duration *and* color discrimination.

Of particular interest for the present purpose is that all kinds of sensory discrimination (e.g., visual and auditory duration discrimination, brightness discrimination, and pitch discrimination) have been found to be associated with activity in the prefrontal cortex. Given the well-established functional relationship between working memory (WM) functions and prefrontal activity (e.g., Owen, 2000; Smith & Jonides, 1999), this activity elicited by sensory discrimination tasks may point to the involvement of WM in the discrimination process (Nenadic et al., 2003). WM is commonly seen as a system serving accessibility and maintenance as well as simultaneous manipulation of mental representations (Barrouillet, Bernardin, & Camos, 2004; Engle, Kane, & Tuholski, 1999). Because, during the discrimination process, a stimulus has to be stored and compared to a second stimulus, this process contains both the maintenance and the manipulation aspect of WM. Furthermore, prefrontal activity during the discrimination process seems not to be specifically related to one type of discrimination task but can be considered to reflect an amodal general process involved in all kinds of sensory discrimination (Ferrandez et al., 2003; Livesey et al., 2007; Nenadic et al., 2003; Pastor, Day, Macaluso, Friston, & Frackowiak, 2004). Consequently, WM-related aspects of the discrimination process might be a central feature of the latent GDA variable derived from different discrimination tasks.

Furthermore, because it is the *shared* variance of several different discrimination tasks which is related to psychometric intelligence and because WM seems to contribute to this shared variance, the close association between GDA and psychometric intelligence might be due to individual differences in WM. This assumption is corroborated by the high correlation between WM and psychometric intelligence (e.g., Ackerman, Beier, & Boyle, 2005; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Kane et al., 2004; Oberauer, Süß, Wittmann, & Wilhelm, 2008; Troche & Rammsayer, 2009a).

Although both WM and GDA represent successful approaches to explain individual differences in psychometric intelligence, only few studies have investigated the interplay among all three constructs. One exception is the study by Demetriou, Mouyi, and Spanoudis (2008) who proceeded from a bottom-up model with lower-order perceptual and sensory processes affecting the efficiency of higher-order cognitive processing. Consistent with this idea, individual differences in basic processes (i.e., perceptual discrimination) contributed to individual differences at higher levels of information processing (i.e., WM) which, in turn, contributed to individual differences in psychometric intelligence defined as the highest level of information processing. In this latter study, however, discrimination ability was assessed with only a single task exacerbating an interpretation at the level of constructs in the sense of GDA.

The present study, therefore, was designed to systematically investigate the interplay among GDA, WM, and psychometric intelligence at the level of latent variables by utilizing different kinds of sensory discrimination tasks, WM tasks, and intelligence scales to establish latent variables representing GDA, WM, and psychometric intelligence. This procedure enabled us to directly compare the following three models of the functional relationship among GDA, WM, and psychometric intelligence:

Model 1 This model proceeds from Spearman's (1904) assumption of a central function which is most prominent in GDA and responsible for individual differences in intelligence as reflected by the high correlation