Intelligence 55 (2016) 69–78

Contents lists available at ScienceDirect

Intelligence

Residual group-level factor associations: Possibly negative implications for the mutualism theory of general intelligence

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ARTICLE INFO

Article history:
Received 2 July 2015
Received in revised form 15 January 2016
Accepted 18 January 2016
Available online 30 January 2016

Keywords:
General intelligence
Mutualism
Factor analysis

ABSTRACT

The mutualism theory of general intelligence (*g*) posits that the positive manifold arises because of mutually beneficial interactions between originally orthogonal cognitive abilities, rather than because of a genuine general construct. In a recent investigation, Gignac (2014) reported that the strength of *g* was largely constant from the ages of 2.5 to 90 years, which was interpreted as an indirect failure to confirm the mutualism theory of *g*. In this investigation, a second indirect test of the mutualism theory of *g* was performed. Specifically, it was hypothesized that, if the extended mutualism theory of *g* is plausible, then there should be some consistent, positive associations between group-level factors, controlling for the effects of a general factor. To examine this possibility, the associations between cognitive ability group-level factors were estimated across a series of seven relatively large and relatively representative samples of intelligence battery data. Next, seven single-factor models were estimated against the seven group-level inter-correlation matrices. The corresponding single-factor residual correlation matrices were observed to yield an approximately equal number of positive and negative residual correlations and an overall mean of zero. Furthermore, the only moderately consistent residual effect was a negative association between crystallised intelligence and processing speed. Although only an indirect test, the results are interpreted to be more supportive of *g* factor theory than mutualism.

For many years, debates about the validity of the general factor of intelligence (*g*) revolved around statistical issues in the context of unrestricted factor analysis. For example, evidence in favor or against the *g* factor could be variously reported, contingent upon the decision to rotate a solution orthogonally, obliquely, or not all (Humphreys, 1979). With the advent of structural equation modeling (SEM), the thorny issue of rotation was circumvented, as the researcher was required to specify a particular structure: a structure which could then be tested against data and evaluated for plausibility, in part, via model fit indices (Bollen, 1989). Based on a number of empirical SEM investigations, there is now broad consensus on the plausibility of a psychometric *g* factor (Sternberg, 2003). However, the precise nature of *g* remains a contentious issue. In particular, some contend that *g* is a genuine construct representative of a meaningful and important human characteristic (Gottfredson, 2002; Jensen, 1998). By contrast, others have contended that the psychometric *g* factor is essentially an epiphenomenon that emerges during development: the mutualism theory of *g* (van der Maas et al., 2006). The purpose of this investigation was to test empirically these two competing theories via an indirect method: residual group-level factor inter-associations.

1. *g* Factor theory vs. mutualism theory of *g*

The *g* factor was originally proposed as a causal explanation for the positive manifold, consistently positive correlations between a diverse collection of cognitive ability tests (Spearman, 1904). Contemporary representations of *g* factor theory do not assert that there is a single factor of intelligence, as originally contended by Spearman (1904, 1923). Instead, it is widely acknowledged that there are approximately 10 group-level factors of intelligence, in addition to *g* (Carroll, 2003). Although the group-level factors of intelligence are a source of active research (e.g., Brunner, 2008; Crawford, Deary, Allan, & Gustafsson, 1998; Frisby & Beaujean, 2015; Tommasi et al., 2015), the *g* factor has been observed to be the most dominant construct associated with a battery of cognitive ability tests, as well the most important with respect to predictive validity (Gottfredson, 2002; Jensen, 2006).

Spearman (1927) theorised that *g* arises due to individual differences in mental energy. Picking up form Spearman (1927); Lykken (2005) contended that *g* arises from individual differences in the ability for sustained concentration, which, presumably, would be aligned closely with the expenditure of mental energy. Based on a series of factor and multidimensional analyses, Marshalek, Lohman, and Snow (1983) argued that the fundamental basis of *g* was cognitive complexity. Jensen (1998, 2006) contended that *g* is probably best not conceptualised as a process. Instead, it is best considered a reflection of physical properties of the brain, which have yet to be identified.

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http://dx.doi.org/10.1016/j.intell.2016.01.007

Correspondingly, psychometric *g* has been reported to be approximately 60% heritable in young adulthood (Haworth et al., 2010). It has also been reported to correlate approximately .30 with brain volume (McDaniel, 2005; Ritchie et al., 2015). Finally, functional neural imaging studies have found that brains that can process information more efficiently tend to be associated with individuals with higher levels of *g* (Haier, 2011).

Several alternatives to *g* factor theory have been articulated over the years (e.g., Anderson, 1992; Bartholomew, Allerhand, & Deary, 2013; Gardner, 1987; Sternberg, 1985; Thomson, 1951). Perhaps the most compelling alternative is the mutualism theory of *g* (van der Maas et al., 2006). The mutualism theory of *g* postulates that the positive manifold arises not because of some general process, but, instead, due to the mutually beneficial interactions that emerge during development between originally orthogonal cognitive processes. Consequently, as the capability of one cognitive process grows, so do others in a mutually beneficial manner through reciprocal causation.

The empirical establishment of the mutualism theory of *g* would have profound implications for the manner in which intelligence is conceptualised and modeled, as it disputes the notion that the positive manifold is caused by a construct (van der Maas et al., 2006). Consequently, a general factor latent variable is considered an inappropriate representation of the positive manifold, according to the mutualism theory of *g*. Instead, a formative model is considered a more acceptable representation of the positive manifold (van der Maas, Kan, & Borsboom, 2014). A formative model does not posit the presence of an entity theorised to explain the observation of a pattern of correlations between subtests (i.e., a construct). Instead, in a formative model, an optimally weighted sum of score based on a battery of subtests is simply a convenient method to create an index. Thus, the observation of a factor with positive loadings of varying magnitudes across several cognitive ability subtests is considered completely meaningless, according to the mutualism theory of *g*. Consequently, an overall intelligence index score based on an optimally weighted sum of cognitive ability subtest scores should be viewed as no more theoretically meaningful than the composite value associated with the Dow Jones Industrial Average index, for example (van der Maas et al., 2014).

Evidently, *g* factor theory and the mutualism theory of *g* are at odds with each other in a fundamental manner. One of the limitations associated with the mutualism theory of *g* is that there are no known methods to test the theory empirically, at least not directly (van der Maas et al., 2006). However, one implication of the mutualism theory of *g* is that the strength of the positive manifold should increase across development, particularly early development, as the mutually beneficial interactions begin to emerge (van der Maas et al., 2006). To test this possibility, Gignac (2014) estimated the strength of the *g* factor (omega hierarchical; Ω_h) across the Wechsler batteries from the ages of 2.5 to 90 years ($N = 5200$). Gignac (2014) reported a largely equally strong *g* factor across age, although the Ω_h index did suggest some increase in the strength of the *g* factor from the ages of 2.5 to 7 years. However, when controlling for the number of subtests within a battery (a characteristic which impacts Ω_h positively), the reduction in the strength of the positive manifold was no longer observed. In fact, the strength of the positive manifold was observed to decrease from about 2.5 to 7 years, which would be inconsistent with the mutualism theory of *g*. Gignac (2014) interpreted the results of his investigation to suggest that the indirect empirical test failed to support the mutualism theory of *g*. Gignac (2014) encouraged others to generate additional approaches to test the mutualism theory of *g*, even if indirectly, in order to evaluate the theory from alternative perspectives.

2. A proposed second indirect test

As a fundamental feature associated with the dynamic mutualism theory of *g* pertains to the mutually beneficial inter-actions between cognitive abilities, it may be suggested that, in order to help evaluate the plausibility of the theory, some focus should be placed upon an examination of the inter-associations between the group-level factors. More specifically, if the mutualism theory of *g* is plausible, then it would seem very unlikely that the postulated pattern of mutually beneficial interactions between group-level factors occur in a manner that is captured perfectly, or nearly so, by a single factor. Instead, one would expect *some* level of shared variance between one or more pairs of group-level factors, independently of a general factor. Furthermore, most of the residual group-level factor associations would be expected to be positive in direction, rather than negative, if the group-level factor associations are the result of mutually beneficial interactions. Admittedly, the conventional correlated factor model is not an entirely accurate representation of mutualism (van der Maas et al., 2006), as only the associations between the group-level factors are estimated in a correlated factor model, rather than their interactions. If there were a SEM model that could be specified to represent the mutualism theory of *g*, the theory could be tested directly. It is in this context that the proposed test described here is considered to be an indirect test of the extended mutualism theory of *g* (see Fig. 1c, van der Maas et al., 2006).

Somewhat surprisingly, very little systematic research relevant to the inter-associations between group-level factors, independent of *g*, has been conducted. Without providing references, Humphreys (1979) asserted that when tested against a heterogeneous battery of cognitive ability tests, a general factor model yields residual correlations mostly near zero. There are, of course, many higher-order model confirmatory factor analytic investigations which have included some group-level factor residual correlations in their models of intelligence. For example, in Gustafsson's (1984) third-order factor model of intelligence, four correlated residuals were included between the lower-order factor residuals. Invariably, however, past studies have included only a small percentage of the total possible correlated group-level factor residual correlations in their higher-order models of intelligence. Moreover, the added residual correlations are typically included in a relatively ad-hoc manner, i.e., in order to simply achieve satisfactory model fit. Consequently, it is difficult, if not impossible, to evaluate the current literature with respect to the associations between group-level factors, independent of *g*, in a comprehensive or systematic manner.

In a recent investigation, Gignac and Watkins (2015) were specifically interested in the unique latent variable association between fluid intelligence and working memory capacity, independently of *g*. In particular, Gignac and Watkins (2015) hypothesized that some level of positive shared variance should be observed between the fluid intelligence and working memory capacity lower-order factor residuals, if the association between these two constructs is special, as commonly asserted (e.g., Carpenter, Just, & Shell, 1990; Fry & Hale, 1996; Oberauer, Su, Wilhelm, & Sander, 2007). Based on a higher-order model and the Wechsler Intelligence Scale for Children — V normative sample (Wechsler, 2014), Gignac and Watkins (2015) reported a non-significant fluid intelligence and working memory capacity residual correlation of −.10 ($p = .152$). Thus, the hypothesis of a special or unique association between fluid intelligence and working memory capacity was not considered supported. From the perspective of the mutualism theory of *g*, the absence of a unique association between fluid intelligence and working memory capacity may be considered at least somewhat inconsistent, as it may be suggested that these two constructs, in particular, would be expected to develop some level of uniquely beneficial interactions over the course of human development. As it was not the focus of their investigation, Gignac and Watkins (2015) did not report any results relevant to the other group-level factor inter-associations, independently of *g*.

Perhaps part of the reason why the unique associations between group-level factors, independent of *g*, have not been examined previously in a comprehensive manner is because it is not possible to identify a higher-order model which includes correlated terms between all of the lower-order factor residuals (Schmiedek & Li, 2004). Such a model