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Hierarchies of factor solutions in the intelligence domain: Applying methodology from personality psychology to gain insights into the nature of intelligence

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ABSTRACT

Research on the structure of psychometric intelligence has used hierarchical models like the higher-order and the bi-factor model and has studied the hierarchical relationship between factors within these models. In contrast, research on the structure of personality has not only used hierarchical models but has also studied hierarchies of factor solutions. We clarify the theoretical and conceptual differences between hierarchical models and the solutions-hierarchy approach used in the field of personality research, and suggest that the solutions-hierarchy perspective can provide a novel perspective for intelligence research. We used the solutions-hierarchy approach to study four correlation matrices ($N = 230$ to 710; 38 to 63 tests), and a large dataset ($N = 16{,}823$; 44 tests). Results provided (a) insights into relationships between intelligence constructs across the hierarchy of factor solutions, and (b) evidence that intelligence has a 1–2–3–5 hierarchy of factor solutions with a g factor at the top, gc and gf factors at the second level, a speed–reasoning–knowledge taxonomy at the third level, and possibly a speed-reasoning–fluency–knowledge–memory/perception taxonomy at the fifth level.

Researchers have long been engaged in efforts to find taxonomies for the major domains of human individual differences. Although a consensus on the structure of a domain of individual differences is not necessarily a prerequisite for scientific progress, knowledge on the structure of a domain of individual differences is commonly helpful for integrating findings within a field and for developing a shared scientific language (e.g., Goldberg, 1993; Goldstein, Zedeck, & Goldstein, 2002; John, Naumann, & Soto, 2008).

Research on the structure of psychometric intelligence started in the first half of the last century (e.g., Spearman, 1904, 1927; Thurstone, 1938a, 1938b). In the following decades, researchers developed a variety of different taxonomies (see Carroll, 1993, for an overview). Over time, most researchers reached a consensus on the idea that an optimal taxonomy for the intelligence domain should be a hierarchical structure with one or more broad abilities at the apex of the hierarchy and one or more levels of narrower abilities arranged below the broad abilities (Lubinski, 2004). This progress notwithstanding, research on the structure of psychometric intelligence is still an active field of research and researchers have continued to investigate the characteristics of the factors at each level of the hierarchy (Carroll, 2003; Goldstein et al., 2002; Johnson & Bouchard, 2005; McGrew, 2009).

A notable difference between studies on the structure of intelligence and recent studies on the general structure of personality is that personality researchers frequently use some techniques and conceptualizations of hierarchy that have not yet been employed in intelligence research. Intelligence research typically relies on two types of hierarchical factor models: the higher-order model and the bi-factor (also known as the nested-factors and the hierarchical) model (e.g., Jensen & Weng, 1994; Yung, Thissen, & McLeod, 1999). Personality researchers have also used these hierarchical models but have additionally used a conceptually different approach that focuses on studying hierarchies of factor solutions (Ashton, Lee, & Goldberg, 2004; de Raad & Barelds, 2008; Markon, 2009; Markon et al., 2005; Saucier, 2009; Saucier & Goldberg, 2001; Zuckerman, Kuhlman, & Camac, 1988). This solutions-hierarchy approach entails a different conceptualization of hierarchy and is frequently used by personality researchers when the focus is on understanding and describing the structure of large datasets. The solutions-hierarchy approach is also sometimes referred to as top-down factor analysis in the personality literature (Ashton, Lee, & Goldberg, 2004; Goldberg, 2006; Waller, 2007).

In this article, we seek to build on personality research and suggest that the methodology frequently used in research on the structure of personality—studying hierarchies of factor solutions—also has implications for research on the structure of intelligence. Our goal is to investigate these implications. We begin this article by clarifying the theoretical and conceptual differences between the hierarchical factor

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models commonly used in intelligence research, and the characteristics of the solutions-hierarchy approach used in personality research. We follow up this conceptual section with analyses of five large datasets on intelligence using the solutions-hierarchy approach. Our article contributes to the literature by (a) clarifying different conceptualizations of hierarchy, by (b) establishing a conceptual link between research on the structure of personality and research on the structure of intelligence, and by (c) complementing existing studies and reviews on the structure of intelligence (e.g., Carroll, 1993).

1. Extant conceptualizations of hierarchy in intelligence research

1.1. The higher-order model

One conceptualization of hierarchy that is frequently used in intelligence research is the higher-order model (e.g., Jensen & Weng, 1994; Yung et al., 1999). Fig. 1a shows a simple higher-order model. In this model, a broad second-order general factor influences three narrower abilities which in turn influence the measurement indicators or tests. One important assumption of this model is the idea that the second-order general factor causally influences the narrower abilities. Another characteristic assumption of the model is that the second-order general factor is not directly associated with the manifest tests or measurement indicators at the lowest level. The effect of the second-order general factor on the tests is mediated by the narrower (or first-order) factors. As a result, the second-order factor in the higher-order model has shared variance with the narrower abilities and this shared variance between the two is assigned to the higher-order factor as the causal source of this variance. The second-order factor also does not share variance with the measurement indicator (the test) that is not also shared between narrower abilities and the measurement indicator.

The higher-order model developed from scientific debate between Louis Thurstone (1939; Thurstone & Thurstone, 1941) and Charles Spearman (1939). Spearman had long argued that the general factor extracted from a large intelligence test battery is a sort of mental energy that is responsible for correlations between tests (Spearman, 1904). In his original two-factor model, Spearman used only one latent variable for the general factor and suggested that the variance in each intelligence test consists of variance due to the general factor g and a specific component that is unique to the specific test. Spearman's two-factor theory is similar to a one-factor model (Harman, 1976; Jensen & Weng, 1994). Thurstone, in contrast, developed a multidimensional view of intelligence and preferred to extract oblique (correlated) factors from intelligence data. Spearman (1939) reanalyzed one of Thurstone's datasets using his two-factor theory. In this reanalysis, Spearman first reduced the number of indicators by aggregating tests that he considered to be similar and only then applied two-factor theory and concluded that the general factor from two-factor theory explained almost all of the correlations in the data between the test aggregates. This approach likely inspired Thurstone to develop the higher-order model by extracting a second-order factor from the correlations of his oblique factors in his later work (Thurstone & Thurstone, 1941). The higher-order model can thus be seen as a compromise between Thurstone's work and Spearman's original idea that the shared variance between a battery of intelligence tests is caused by a general factor, or g (Jensen & Weng, 1994; Lang, Kersting, Hülsheger, & Lang, 2010).

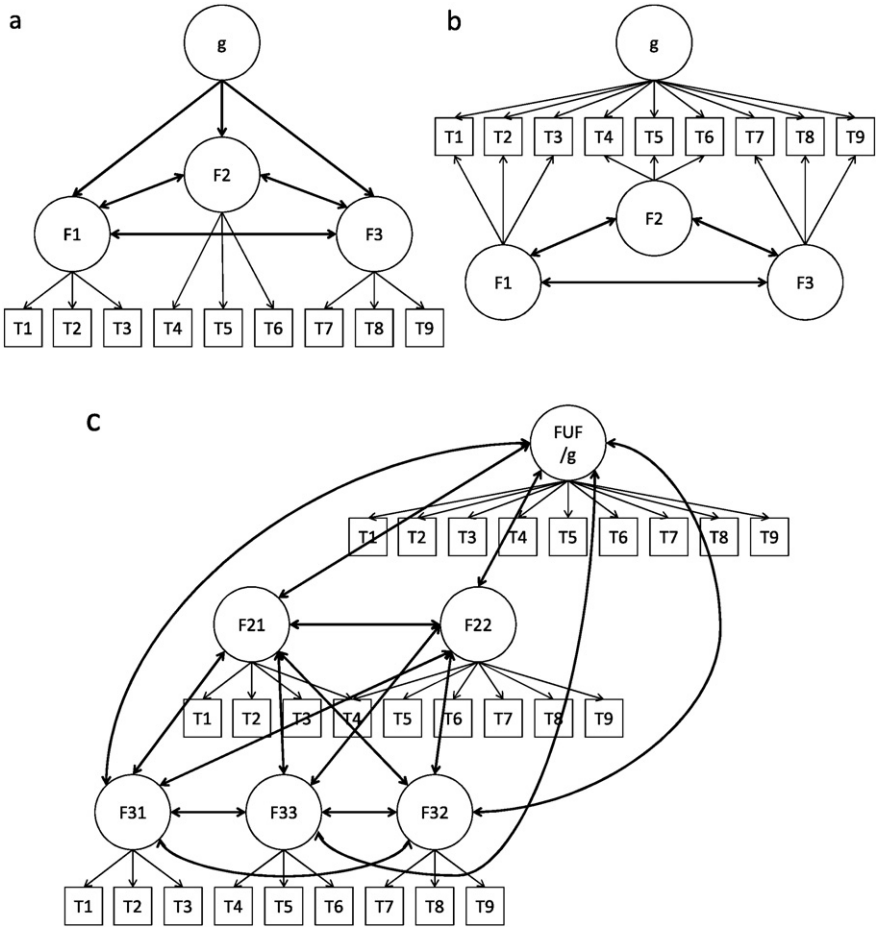

Fig. 1. The higher-order model and the bi-factor model are shown in (a) and (b), respectively. These models seek to find the most parsimonious hierarchical solution. In contrast, the hierarchies of factor solutions approach shown in (c) separately extracts solutions with different numbers of factors from the same indicators and then studies correlations between these factors and represents a different analytical strategy. FUF = first unrotated factor.