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On the interpretation of the CHC factor Gc ☆

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ABSTRACT

On the one hand, the factors Gf and Gc in the Cattell–Horn–Carroll (CHC) model of intelligence are hypothesized to represent individual differences in unique psychological or biological capacities. On the other hand, they are interpreted as representing the theoretical variables fluid and crystallized intelligence in investment theory. With respect to Gc, this leads to a theoretical conflict because in investment theory crystallized intelligence is not a capacity but purely a statistical entity. We contend that if CHC factor Gc represents a capacity, it cannot represent crystallized intelligence, and if Gc represents crystallized intelligence, it does not represent a capacity. In addition, from our discussion of Gc, we conclude that in investment theory the factors Gf and *g* represent one and the same capacity. In support of our theoretical conclusions, we implemented the CHC model in a confirmatory factor analysis of a HCA (Human Cognitive Abilities project) data set. As expected, Gf and *g* were statistically indistinguishable. Gc was effectively absent, because it was statistically equivalent to verbal comprehension. Factors Gc and *g* could be removed from the model without any reduction in model fit. We argue that in the CHC taxonomy the factors Gc and *g* are redundant as explanatory variables.

The scientific status of factors of intelligence has been the subject of considerable discussion. Although most discussions focus on the general factor of intelligence (see e.g., Dickens, 2008; Bartholomew, Deary, & Lawn, 2009; van der Maas et al., 2006, for recent discussions), theoretical discussion of other factors of intelligence is also warranted. For example, after reviewing 20 years of factor analytic research on intelligence 'from a Cattell–Horn–Carroll (CHC) perspective', Keith and Reynolds (2010, p. 643) conclude that "Gc remains an elusive construct, and researchers often talk past each other when discussing Gc, with it being referred to as crystallized intelligence, academic achievement, verbal ability, or comprehension/knowledge, to name a few […] Clarification about the nature of Gc versus verbal ability and achievement would be useful". In the present paper, we discuss the interpretation of the CHC factor Gc with the aim of clarifying its nature. In doing so, we also discuss the nature of the CHC factors Gf, and *g*. The discussion is limited in the sense that it concerns the (possibly causal) interpretation of factor analytic results in the CHC model. Although the CHC model has been established over many years of research (see Keith & Reynolds, 2010; McGrew, 2009 for overviews) and is considered to be well validated (McGrew, 2009), there are of course other useful models, such as the VPR model (Johnson et al., 2007; Johnson & Bouchard, 2005), which is an extension of Vernon's (1964, 1965) verbal–perceptual model. We return to this briefly below. In this paper, we use the CHC as a working model. That is, we discuss the situation *given* a researcher accepts the CHC model and wants to interpret factor analytical results.

From the statistical point of view, the common factors in factor models of intelligence represent the common variance among test scores. The CHC model, which is a synthesis of Cattell and Horn's extended 'Gf–Gc model' (Cattell, 1987; Horn, 1968, 1991; Horn & Stankov, 1982) and Carroll's (1993; 1996) 'three-stratum model', is thus in the first place a

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taxonomy of statistical factors. However, substantively, these factors are often interpreted in terms of substantive underlying variables, for example psychological capacities. Carroll (1996, p. 15), for instance, stated: "…underlying each factor [of the three-stratum model] there is a specific state or substrate that exists in the individual and that accounts for his or her ability or inability to perform tasks in which that ability is called for". Although factor analysis may support such substantive, realist, interpretation of common factors, it cannot prove that this interpretation is correct (see Bartholomew, 2004; Borsboom & Dolan, 2006; Borsboom & Mellenbergh, 2002; van der Maas et al., 2006). Hence, the substantive interpretation of the results of factor analysis, e.g., the interpretation of a given common factor as a psychological capacity, has to be based on theoretical considerations. So, in order to interpret the factors in the CHC model as representing underlying capacities one needs a (CHC) theoretical framework.[4]

Concerning the theoretical status of the factors in CHC model, there is some disagreement among researchers, including Cattell, Horn, and Carroll (despite the fact that they largely agreed with the statistical structure of intelligence). Consider the following example. In the CHC model the second order factors are positively intercorrelated, which opens the possibility of positing a general intelligence factor at the apex of the hierarchy. The three-stratum model includes such a factor (*g*), but the Gf–Gc model does not. This has the following theoretical background. Whereas Carroll (1998) took a realist position concerning the general factor by interpreting it as a unique cognitive capacity, Horn (e.g., Horn & Noll, 1997) rejected this realist interpretation and viewed general intelligence as merely a statistical entity; Horn considered it to be nothing more than an aggregate of various cognitive capacities. Another theoretical disagreement concerns the factor Gc. Whereas Carroll (1993) stated that it is a matter of preference whether Gc is interpreted as verbal ability or as crystallized intelligence, Cattell (1987) maintained that verbal ability and crystallized intelligence are distinct variables.

The present aim is first to discuss the theoretical status of CHC factor Gc as representing (a) crystallized intelligence, and (b) a substantive underlying variable (a psychological capacity). The paper is organized as follows. As the conceptualization of a latent variable is central to our discussion, we first outline the different views one may entertain with respect to a latent (underlying) variable. Next, because the link between the investment theory of fluid and crystallized intelligence and the CHC model is not self-evident, we present brief reviews of investment theory and (the development of) the CHC model. From these reviews, we conclude that crystallized intelligence is purely a statistical entity, and that the investment hypothesis in itself does not explain why crystallized intelligence should appear as a separate factor (Gc) in a factor analysis. In our discussion it also becomes clear that in investment theory fluid and general intelligence represent the same capacity. The question remains what meaning to attach to the finding in factor analysis of the distinct factor commonly designated Gc. Next, in the light of investment theory, we review multiple interpretations of factors denoted Gc as given in the literature. We conclude that if Gc is interpreted to represent a capacity (realist position), it cannot represent crystallized intelligence, and if Gc is interpreted as representing crystallized intelligence (nonrealist position), it does not represent a capacity. We contend that from a realist position Gc in most cognitive batteries represents individual differences in verbal comprehension.

Our second aim is to investigate our conclusions empirically. To this end, we implemented the CHC model in confirmatory factor analysis (Carroll, 1993). As, predicted, Gc was found to be statistically indistinguishable from a verbal comprehension factor, and Gf, the variable that represented individual differences in fluid intelligence, was statistically indistinguishable from the factor *g*. Gc and *g* could be removed from the CHC factor model without any reduction in model fit. We end with a general discussion. Our final conclusions are that Gc does not represent a unique capacity and that Gf and *g* represent one and the same (reasoning) capacity; within the CHC theoretical framework Gc and *g* are redundant as explanatory variables.

1. The interpretation of a latent variable

The substantive interpretation of latent variables, as encountered in factor analyses, requires a theoretical framework that should include one's conceptualization of the nature of latent variables. However, the term latent variable is used in more ways than one (Bollen & Lennox, 1991; Borsboom, Mellenbergh, & Van Heerden, 2003). Firstly, the term latent variable can refer to a formal, mathematical concept, which is used in mathematical treatments of measurement and Structural Relation Modeling (SEM). It is usually symbolized by a letter, e.g., θ in Item Response Theory, or η in SEM. Beyond the mathematical treatment the formal concept has no meaning, i.e., it does not reveal anything about reality. Secondly, the term latent variable can refer to an operational concept, which is the result of an algebraic function of observed scores, e.g., a weighted sum score, like a full-scale IQ score. The factors extracted from a test battery (e.g., the CHC factors) represent instances of the operational concept. Since there is nothing latent about an algebraic function, there is nothing latent about the operational concept. The link between the formal concept (label) and operational concept (algebraic result) requires theoretical interpretation. An example of this is '*g* represents individual differences in general intelligence, and a part of the common variance in intelligence tests scores corresponds to individual differences in general intelligence'.

With respect to the theoretical interpretation of the link between formal concept (label) and operational concept (algebraic result), there are essentially two philosophical positions (Borsboom et al., 2003). First, one can take a nonrealist position, which holds that operational variable (algebraic result) is nothing more than a construction of the scientist. It implies that different IQ batteries may measure or estimate the same variable (or set of variables), but that this variable need not be attributed existence independent of the scientist's interpretation. Second, one can take a realist position. A realist position holds that the

[4] Similarly, to interpret the factors in the VPR model as substantive underlying variables, one needs a VPR theoretical framework.