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On the relationship between executive functions of working memory and components derived from fluid intelligence measures☆

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ABSTRACT

The aim of the current study is to provide new insights into the relationship between executive functions and intelligence measures in considering the item-position effect observed in intelligence items. Raven's Advanced Progressive Matrices (APM) and Horn's LPS reasoning test were used to assess fluid intelligence which served as criterion in investigating the relationship between intelligence and executive functions. A battery of six experimental tasks measured the updating, shifting, and inhibition processes of executive functions. Data were collected from 205 university students. Fluid intelligence showed substantial correlations with the updating and inhibition processes and no correlation with the shifting process without considering the item-position effect. Next, the fixed-link model was applied to APM and LPS data separately to decompose them into an ability component and an item-position component. The results of relating the components to executive functions showed that the updating and shifting processes mainly contributed to the item-position component whereas the inhibition process was mainly associated with the ability component of each fluid intelligence test. These findings suggest that improvements in the efficiency of updating and shifting processes are likely to occur during the course of completing intelligence measures and inhibition is important for intelligence in general.

1. Introduction

The relationship between working memory and intelligence has been in the focus of scientific research for quite a long time. Already in the 1990s it has been obvious that there is a substantial relationship between them (Carpenter, Just, & Shell, 1990; Kyllonen & Christal, 1990). Over the years further evidence has accumulated and provided the basis for a comprehensive meta-analysis that indicates a moderately strong relationship between working memory and intelligence (Ackerman, Beier, & Boyle, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005). There is even research work suggesting almost equivalence between the two constructs (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004).

Since the beginning of research on the relationship between working memory and intelligence, the concept of working memory has undergone a considerable change. In the beginning it was Baddeley's (1986) concept of working memory that was mainly reflected in the research on this relationship. This concept suggests a substructure consisting of the central executive, the visual sketchpad and the phonological loop. In research, special emphasis has been given to the central executive serving a number of different functions in human information processing. Subsequently the focus of research has shifted from the central executive to executive control (Logan & Gordon, 2001). Executive control is expected to focus the cognitive processing on the task that needs to be accomplished. Additionally executive control is assumed to ensure that task goals are actively maintained and to prevent deviations from the processing plan due to other distracting stimuli (Engle & Kane, 2004). Furthermore, the concept of executive control is in line with the concept of executive attention that refers to the control and supervision of subordinate processes of stimuli selection. This type of attention has been found to be a second-order type of attention that underlies a host of first-order attention types (Schweizer, 2010).

1.1. The conceptual elaborations regarding executive control

More recently the focus of research has concentrated on functions of executive control: the executive functions (EFs) mainly referred mainly to as updating, shifting, and inhibition (Miyake & Friedman, 2012). These EFs have been described as general-purpose control mechanisms

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that are assumed to regulate the dynamics of human cognition and action. They are even regarded as core components of the self-control and self-regulation ability and, therefore, are assumed to significantly influence everyday life (Moffitt et al., 2011).

It has been argued that completing tasks that are demanding to executive control are frequently characterized by one or several intermediary states which need to be arrived at before reaching the final state. According to Morris and Jones (1990), this type of mental processing includes the monitoring of task-relevant information at hand and the manipulation of the contents of working memory. An important function is that older information no longer necessary is replaced with newer information. This kind of processing characterized by the succession of various intermediary states highlights updating as a major function of executive control (Bledowski, Rahm, & Rowe, 2009). There is already some evidence of a substantial relationship between updating and intelligence (Friedman et al., 2006). There is also evidence obtained by means of various versions of the star counting test that asks participants to continuously update the number of stars maintained in working memory (e.g., De Jong & Das-Smaal, 1995; Ren, Altmeyer, Reiss, & Schweizer, 2013). Furthermore, performance in completing the exchange test as a working memory measure that requires participants to update the mental positions of neighboring figures of an array has also been shown to correlate with measures of fluid intelligence (e.g., Schweizer, 2007).

The other important function of executive control referred to as shifting extends to the executive operations that perform the shifts between the demands of multiple tasks or mental sets (Miyake et al., 2000). The ability to conduct this kind of shifting operation is considered as one of the essential characteristics of mental information processing according to models of attention control like the supervisory attention system by Norman and Shallice (1986). In studies of this research area shifting is investigated by means of the so-called set switching paradigm (Allport, Styles, & Hsieh, 1994). Such switching tasks have also been used in studies on the relationship between cognitive performance and intelligence. Some of these studies report a substantial correlation between shifting and intelligence (e.g., Salthouse, Fristoe, McGuthry, & Hambrick, 1998). The findings by other studies do not support such a relationship (Friedman et al., 2006; Rockstroh & Schweizer, 2001).

Finally, there is inhibition considered as the third major function of executive control. The concept of inhibition has a long history in various areas of psychology and has frequently been considered as closely related to interference control (Friedman & Miyake, 2004). Inhibition is thought to suppress external and internal stimuli or impulses that potentially distract the focus of cognitive processing away from the task goal (Nigg, 2000). It is crucial for overriding dominant or prepotent responses (Friedman & Miyake, 2004). Inhibition is considered as essential “for normal thinking processes and, ultimately, for successful living” (Garavan, Ross, & Stein, 1999, p. 8301). The results regarding the relationship between inhibition and intelligence are mixed. The analysis of the results of several studies regarding the relationship between inhibition and intelligence led Dempster (1991) to conclude that there must be an association of intelligence with inhibition. Salthouse, Atkinson, and Berish (2003) also provide evidence in favor of the relationship. However, a more recent study indicates that there is no such relationship (Friedman et al., 2006).

1.2. The complication regarding fluid intelligence measures

The concept of fluid intelligence was proposed by Horn and Cattell (1966) and has found its way into almost all major models of intelligence, as for example, Carroll's (1993) three stratum model of cognitive ability and the Cattell–Horn–Carroll theory of cognitive abilities (McGrew, 2005). Furthermore, research reveals that there is an especially close relationship between fluid intelligence and general intelligence (Kvist & Gustafsson, 2008). Because of this property fluid intelligence often serves as an indicator of general intelligence in investigating the relationship between intelligence and other constructs.

Although measures of fluid intelligence are considered as homogeneous, research on the item-position effect has revealed inhomogeneity, and the observed inhomogeneity may call the validity of a host of findings regarding fluid intelligence into question. The item-position effect refers to the dependency of the response to a specific item in a sequence of homogeneous items on the position of this item within the sequence. The research regarding the item-position effect started in the 1950s (Campbell & Mohr, 1950; Mollenkopf, 1950). Initially it was experimental research. A major result of this research was that items assigned to the latter part of a series of items show a larger item reliability than items assigned to the former part (Hartig, Hölzel, & Moosbrugger, 2007; Knowles, 1988; Knowles & Byers, 1996). The item-position effect was also observed in ability items by means of item response theory techniques (e.g., Debeer & Janssen, 2013; Embretson, 1991; Verguts and De Boeck, 2000) and by means of factor-analytic methods (e.g., Hartig et al., 2007; Schweizer, 2012).

In the factor-analytic framework, confirmatory factor analysis (CFA) is conducted since it allows the decomposition of the variance into two subcomponents (Schweizer, 2012). Factor loadings are constrained in such a way that they account for a systematic increase of the latent variance. The expectation of an increase of systematic variance has grown out of Knowles' (1988) and others' observations of an increase in reliability that means an increase in the relative amount of systematic variance from the first to last items. That is, if the data are collected by means of a fluid intelligence measure, the method yields two components: the ability component and the item-position component (Ren, Wang, Altmeyer, & Schweizer, 2014; Schweizer, 2012). The ability component represents the basic part of the measure that can be considered as purified fluid intelligence. This component has been shown to correlate almost perfectly with general intelligence (Schweizer, Troche, & Rammsayer, 2011). Separating the item-position component from data of an intelligence test may result in higher correlations of external constructs with the ability component than with the raw score of the intelligence test (e.g., Ren et al., 2014).

The two components achieved by decomposing data on Raven's Advanced Progressive Matrices (APM) have been related to measures of learning by Ren et al. (2014) since there is the hypothesis that the item-position effect is due to learning (Embretson, 1991; Verguts & De Boeck, 2000). According to the results of this study the item-position component is closely related to complex learning, that is, for example, characteristic of learning mathematics (Ren et al., 2014). In contrast, simple learning referred to as associative learning proved to show a moderate relationship with the ability component.

Since the ability and item-position components of an intelligence measure show different properties, as for example different relationships with learning, it can be expected that they relate to measures of EFs in different ways. There is already one study demonstrating that the position component, but not the ability component of APM, is related to executive attention (Ren, Goldhammer, Moosbrugger, & Schweizer, 2012). However, this study used a number of attention tasks such as those from the Test for Attention Performance (Zimmermann & Fimm, 2000), and from the Multidimensional Attention Test Battery (Heyden, 1999) to assess executive attention. Although completing these attention tasks requires executive control, Ren's study has not identified particular attention functions that characterize these attention measures. Therefore, it remains an open question which one of the EFs (e.g., updating, inhibition, and shifting) is related to the position component of an intelligence measure. Furthermore, it is unclear whether new results considering the item-position effect are in line with previous results regarding the relationship between EFs and fluid intelligence.

1.3. The present study

The major objective of this study is to provide new insights into the