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Process-based account for the effects of perceptual attention and executive attention on fluid intelligence: An integrative approach ☆

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ABSTRACT

Perceptual attention and executive attention represent two higher-order types of attention and associate with distinctly different ways of information processing. It is hypothesized that these two types of attention implicate different cognitive processes, which are assumed to account for the differential effects of perceptual attention and executive attention on fluid intelligence. Specifically, an encoding process is assumed to be crucial in completing the tasks of perceptual attention while two executive processes, updating and shifting, are stimulated in completing the tasks of executive attention. The proposed hypothesis was tested by means of an integrative approach combining experimental manipulations and psychometric modeling. In a sample of 210 participants the encoding process has proven indispensable in completing the tasks of perceptual attention, and this process accounted for a considerable part of fluid intelligence that was assessed by two figural reasoning tests. In contrast, the two executive processes, updating and shifting, turned out to be necessary in performance according to the tasks of executive attention and these processes accounted for a larger part of the variance in fluid intelligence than that of the processes underlying perceptual attention.

1. Introduction

The relationship between the measures of attention and intelligence is especially complicated because of the diversity of the types of attention, which are assumed to be associated with different cognitive processes (Coull, 1998). There are some types of attention (e.g., alertness, focused or selective attention) mainly concentrating on the perceptual aspect of mental processing. These types of attention yielded mixed findings when related to higher-order cognitive abilities (e.g., Lansman, Poltrock, & Hunt, 1983; Schweizer, Moosbrugger, & Goldhammer, 2005; Stankov, 1983). Furthermore, during the last decades the emerging interest in working memory has gradually extended the concept of attention from the area of perception to higher mental processing, which gave rise to the concept of executive attention (Conway, Kane, & Engle, 2003; Engle, Tuholski, Laughlin, & Conway, 1999). Moreover, perceptual attention and executive attention are clearly circumscribed in an empirical study (Moosbrugger, Goldhammer, & Schweizer, 2006) indicating that these two aspects of attention serve as higher-order attention types derived from a number of first-order attention types. Both perceptual attention and executive attention showed considerable influences on fluid reasoning in a recent study (Ren, Goldhammer, Moosbrugger, & Schweizer, 2012).

However, despite those recent advances, a complete account of the effects of perceptual attention and executive attention on intelligence is still of great necessity. Previous research focusing on attention and intelligence has been dominated by the differential approach that is typified by using correlation and correlation-based statistical techniques. While this approach may be effective in generating successful models for the structure of the relationship concerning attention and intelligence (e.g., Schweizer et al., 2005), it does not contribute much to advance our knowledge concerning the nature of the relationship, i.e., which factors or, more specifically, which cognitive processes underpin the relationship between the constructs. In this situation an additional consideration of the experimental approach (Cronbach, 1957, 1975; Deary, 2001) may be helpful in uncovering the underlying factors. Therefore, based on an integrative approach combining experimental and differential approaches, the present study aims to identify the underlying processes in both perceptual attention and executive attention, to compare the influences of these processes on intelligence so as to reveal the essential differences between these two higher-order types of attention and their differential effects on fluid intelligence.

1.1. The distinction of perceptual attention and executive attention

Perceptual attention and execution attention can be distinguished by different theoretical accounts within attention research, most of

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which concentrate on either perceptual attention or executive attention. Attention in perceptual processing has dominated the first modern model of attention proposed by Broadbent (1958) who emphasized the processing of particular stimuli when there are multiple information sources. Posner and Boies (1971) followed this tradition in their multicomponent model of attention that distinguished between alertness and selectivity within perceptual tasks. Consistent with this line, there was also the theory of visual attention (TVA) (Bundesen, 1990) arguing that the selection of stimuli is based on perceptual categorization. Attention as executive control has arisen along with working memory research (Baddeley, 1986) since the central executive of working memory was conceptualized according to the supervisory attention system (SAS) (Norman & Shallice, 1986). Similarly executive attention was characterized as controlled processing (Schneider & Shiffrin, 1977), which is essential to ensure that task goals are actively maintained, and to prevent attention being captured by other distracting stimuli (Engle & Kane, 2004).

Logan and Gordon (2001) have given a more elaborate description of the distinction between perceptual and executive aspects of attention in their theory of executive control. According to their theory, the perceptual aspect refers to the subordinate processes of stimulus selection according to TVA (Bundesen, 1990) whereas the executive aspect refers to the control and supervision of the subordinate processes. Consistent with this theory, the study conducted by Moosbrugger et al. (2006) suggested that perceptual attention and executive attention account for most of the individual differences in attention measures. Therefore, it is quite reasonable to concentrate on these two higher-order types of attention when investigating the underlying processes accounting for the effect of attention on intelligence.

1.2. Suspected processes driving the effect of attention on intelligence

In searching for sources accounting for the effect of attention on intelligence, it is advisable to concentrate on cognitive processes that are critical in attention performance, while being known from available literature as bases of human intellectual differences. Characteristics of perceptual attention suggest an encoding process that plays a major role in grouping and storing task relevant information into working memory (Primi, 2001). In the case of executive attention, the conceptual overlap with the central executive of working memory (Baddeley, 1986; Norman & Shallice, 1986) provides a reasonable ground to concentrate on typical executive processes that are well established in both attention and working memory research. Processes of interest in this study are mental updating and mental shifting.

Although the term encoding has several possible meanings, in this paper it refers to the process of transforming perceptual input into organized or categorized information that is temporarily stored for further processing (Primi, 2001). This perceptual grouping of task relevant information captures the key characteristics of perceptual attention delineated by Bundesen (1990). Furthermore, the perspective of perceptual attention additionally highlights the modifiability of encoding as the adjustment of the focus of attention that reflects the momentary attention orientation, i.e., there is modulation of the scope of attention by encoding the way that information is stored in working memory (Cowan et al., 2005; Oberauer, 2002).

It has been argued that the success in performing executive attention tasks requires not just representations of the categorized stimuli, but also the updating of the focus of attention (Bledowski, Rahm, & Rowe, 2009; Unsworth & Engle, 2008). This updating function appears to be closely associated with the updating processes specified as the central executive by Baddeley (1986). Morris and Jones (1990) have further suggested that this mental process takes its part in monitoring task-relevant information at hand and, more importantly, manipulating the contents of working memory by replacing old, no longer relevant information with newer, more relevant information. The operation of this updating process seems evident in performing a working memory task denoted the Exchange Test (Schweizer, 1996). This test requires participants to mentally update the mental positions of the neighboring figures of an array until achieving the same sequence of figures as a second array. Several studies using this test indicated a correlation of approximately .50 with measures of fluid intelligence (e.g., Schweizer, 1996, 2007).

Mental shifting, as defined by executive operations of shifting back and forth between multiple tasks or mental sets (Miyake et al., 2000), has been popular in studies of attention by means of set switching paradigms (Allport, Styles, & Hsieh, 1994). The ability to shift mental sets has been considered as one of the essential operations in the models of attention control like SAS (Norman & Shallice, 1986). There are studies employing the switching tasks reporting substantial correlations with intelligence measures (e.g., Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). In addition, the results of a few studies employing the Star Counting Test (De Jong & Das-Smaal, 1995), an established attention test mainly tapping the shifting process due to the switching or alternation between forward and backward counting, suggested that executive attention contributed considerably to account for the individual differences of fluid intelligence (e.g., De Jong & Das-Smaal, 1995; Ren et al., 2012).

Besides the suspected processes elaborated above, it is necessary to refer to the state of alertness, a non-process component of attention that is consistently identified as one basic component of attention (e.g., Posner & Boies, 1971; Sturm & Willmes, 2001). Alertness denotes a general level of response readiness that enables a faster response to sensory stimuli due to self-initiated preparation or external signals indicating the imminent occurrence of a stimulus (Sturm & Willmes, 2001). Thus it is likely that the state of alertness influences processing speed in measures of basic attention requiring perceptual processing in the first place. Therefore in this study the state of alertness is included as an indispensable component of perceptual attention when exploring the role of the encoding process in accounting for the effect of perceptual attention on fluid intelligence.

1.3. An integrative approach

Next, the question arises of how to control and separate the suspected processes on one hand and to investigate the influences of those processes on the relationships of perceptual attention and executive attention with intelligence on the other hand. As indicated previously, an efficient way to stimulate the underlying processes is to systematically manipulate the demands for information processing in such a way that a particular process is affected by the manipulation whereas the others are not. The experimental manipulation leads to several treatment levels demonstrating systematic differences in reaction times or accuracy due to the influence of the affected process or factor within a cognitive task. At the same time there are other implicated processes independent of the differences of the treatment levels. The differential effects of the experimental manipulation on the underlying processes of a task provide a favorable condition for the isolation and separation of the multiple processes by means of statistical methods. Structural equation modeling (SEM) has the capacity to decompose the variance associated with the treatment levels into one component reflecting the source (or process) stimulated by the experimental manipulation and the other component reflecting the non-experimental sources.

However, it is necessary to note that the decomposition of variance associated with the treatment levels cannot be guaranteed by standard SEM. In the standard model factor loadings linking the manifest and latent variables are freely estimated, which are not particularly suitable for representing the systematic differences between the treatment levels. The statistical model suited for this purpose is the fixed-links model (Schweizer, 2008), which shares the mathematical foundations with early growth curve models (Meredith & Tisak, 1990). The main characteristic of the fixed-links model is that it