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How well can storage capacity, executive control, and fluid reasoning explain insight problem solving

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ABSTRACT

Previous studies have found discrepant results on the relationship between insight problem solving and the processes underlying analytic thinking: storage capacity, executive control (two components of working memory; WM), as well as fluid reasoning. Some research showed that WM and/or reasoning are positively related to insight, supporting the "nothing-special" account, whereas other studies demonstrated null or negative relationships favoring the "special-process" view. This study examined a large sample with a battery of insight, reasoning, and WM tasks, to estimate the pattern of links between investigated constructs using structural equation modeling. WM and reasoning together explained about two thirds of the variance in insight. Both WM components similarly contributed to insight. WM's contribution was mediated by reasoning. These results support the nothing-special view. However, after WM variance was partialed out, the link between insight and reasoning substantially weakened, that makes room for the special-process view. Both accounts can be integrated in the view that insight is "nothing special with special add-ons" – the latter understood as the processes and strategies specific only to insight problem solving.

1. Introduction

Insight in problem solving consists of a sudden (non-incremental, unexpected) realization of a problem's solution, preceded by a time in which the problem solver gets stuck in a mental cul-de-sac, usually due to adopting misleading initial problem representations and/or using inadequate problem solving strategies. Sometimes, the experience of insight may directly follow a time interval in which the problem has been put aside (i.e., incubation). The importance of insight phenomenon as a scientific problem arises from at least two facts. First, really valuable problem solutions, that is, genuinely novel and substantial contribution to the progress of our civilization (i.e., society, science, technology, culture), often seem to involve insights (Ohlsson, 2011). Second, even though the processes responsible for non-insight analytical problem solving (e.g., fulfilling the Tower of Hanoi task or a fluid reasoning test) has already been understood to a certain extent, and while the intensive research on insight has continued for a century, the precise cognitive and neural mechanisms underlying insight still escape a satisfactory explanation (Weisberg, 2014).

The existing experimental research on insight led cognitive science and psychology to formulate two main accounts of the processes leading to insights. One approach, initiated by the Gestalt psychologists (e.g., Duncker, 1945; Maier, 1930; Walas, 1926), but extended largely afterwards (e.g., Metcalfe & Weibe, 1987; Ohlsson, 2011), explains insightful problem solving as resulting from the complete change in the problem solver's mental representation of a problem. According to this approach, adopting a new perspective on a given insight problem is necessary, because originally such a problem induces an improper, stereotypical representation/problem solving strategy that might be effective in the case of analytic problems, but cannot succeed for insight problems. For

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example, an influential *representational change theory* proposed by Ohlsson, Knoblich, and their colleagues (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; Ohlsson, 1992) assumes that unsuccessful attempts to solve a problem are followed by the re-representation of a problem, including the relaxation of unnecessary constraints (e.g., fixations) that limit the space of possible solutions as well as the recoding (decomposition) of chunks underlying the initial problem representation into more meaningful chunks. The relaxation and decomposition processes may act on a local level (e.g., by eliminating particular constraints), however, the changes influencing the global aspects of problem representation lead to correct insights most effectively (but they are also the most difficult). In total, the above "special-process" view treats insight problem solving as a qualitatively different process than analytic problem solving (also see Bassok & Novick, 2012; Ohlsson, 2011).

The alternative account of insight, often called either the "business-as-usual" or "nothing-special" approach, assumes that insight problem solving is based on the same elementary processes (e.g., perception, imagination, attention, memory, learning) that also underlie non-insight thinking, but one difference is that in the former case the subjective experience of (i.e., the conscious access to) a solution has an all-or-none nature. In other words, according to this approach, in insight problems the mind is constantly closing the gap between initial and final problem state, exactly as in analytic problems, but unlike in the latter problems this fact enters consciousness just before the final state is reached. According to the nothing-special approach, sole re-representation will not suffice: Some analytic processes are also needed to discover what a new representation should be, and others are necessary to further elaborate such a representation into the complete solution (Perkins, 1981; Weisberg & Alba, 1981). For example, in this vein, the *progress monitoring theory* (MacGregor, Ormerod, & Chronicle, 2001) proposes that people start and continue solving insight problems with a hill-climbing strategy (usually a useful one in analytic thinking). Insights are possible only when the problem solver can represent in her or his working memory (WM) – that is, in the "engine" of cognition in which the goals and sub-products of thinking are actively maintained and transformed – the whole hill-climbing path available to her or him (to "look ahead"). Only then she or he can determine that this path cannot lead to the correct solution. So, high WM capacity (WMC), which allows one to look ahead to a larger extent, may lead to more probable insights than low WMC.

One way to test the nothing-special approach against the special-process view is by means of psychometric studies that examine the links between the scores on insight problems and the effectiveness of more "ordinary" analytic processes. Indeed, significant correlations were found between the former and the latter. For instance, insight correlated with fluid reasoning (Davidson, 1995), attentional selection (Davidson & Sternberg, 1995), and – most importantly – the various aspects of WM (e.g., Chein, Weisberg, Streeter, & Kwok, 2010; Fleck, 2008; Gilhooly & Fioratou, 2009; Murray & Byrne, 2005). Following this line of studies, the main goal of the present study is to precisely evaluate the link between insight problem solving and WM and analytical reasoning, that is, to establish how much variance in insight can be explained by appealing to reasoning and WM.

Specifically, I will contrast the contribution to insight of two commonly separated (empirically as well as conceptually) aspects of WM: *storage capacity* versus *executive control over WM*. Storage capacity (short-term memory; STM) is most often conceptualized as the number of representations than can be actively maintained/bound in WM (e.g., Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Cowan, 2001). Storage capacity may constrain fluid reasoning because the number of distinct items simultaneously held in active memory influences the number of relations that can be set between these items, resulting in differences in the complexity of reasoning process that an individual is able to carry out (Halford, Cowan, & Andrews, 2007; Halford, Wilson, & Phillips, 1998). The number of processed relations may also be constrained by the setting of flexible, temporary bindings between chunks held in WM, or between them and their corresponding positions within some mental structure (i.e., not only by the capacity to maintain those chunks; Oberauer, Süß, Wilhelm, & Wittman, 2008). For example, such a structure may consist of links between items and their serial positions during recall, as well as abstract placeholders in some schema or solution's representation. Storage capacity may also constrain some representations crucial for finding insightful solutions, for instance by limiting the generation of the above-mentioned hill-climbing path, which might allow seeing that following this path will be fruitless (and thus some reconfiguration is needed).

Executive control is a crucial WM mechanism that includes endogenous directing attention, blocking distraction, and inhibiting responses (e.g., Burgess, Gray, Conway, & Braver, 2011; Kane, Conway, Hambrick, & Engle, 2007). For example, the executive-attention theory (e.g., Kane et al., 2007) suggests that individual performance in both WM tasks and reasoning tests depends on the quality of domain-general control over attention. It has been suggested that correct reasoning relies on the effective focusing of attention on task relevant information, and on the blocking of potential distraction. Subjects with low attention control capabilities suffer from poor maintenance of task goals, and they are frequently captured by irrelevant stimuli and/or processes. In the case of insight problem solving, efficient control over attention may help in blocking fixations, or ease the switching between alternative representations of an insight problem. However, it also has been proposed that too much attention control (too much focusing on the initial problem representation) may harm creative problem solving (Wiley & Jarosz, 2012).

Each of two WM aspects discussed may be differently related to some high-level cognitive function. For example, in my recent studies it appeared that storage capacity more strongly predicts analytic reasoning (fluid intelligence) than does executive control (e.g., Chuderski, 2014; Chuderski & Necka, 2012; Chuderski, Taraday, Nęcka, & Smoleń, 2012; for similar conclusions see also Carpenter, Just, & Shell, 1990; Colom et al., 2008; Oberauer et al., 2008; Shipstead, Lindsey, Marshall, & Engle, 2014). So, it is interesting whether a similar or different contribution of those two aspects of WM can be found in the case of insight.

I start by reviewing existing psychometric studies on insight, in order to show that so far a satisfactory explanation of the nature of WM-insight link has not been provided, and the problem definitely calls for additional data. Then, I present a large-sample and multiple-task study, in which the powerful