The Role of Working Memory on Fluid Intelligence

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Abstract: Previous research proved that working memory is closely related to fluid intelligence, but the role of working memory on fluid intelligence is unclear. This review summarizes previous studies to explore the core mechanism of working memory which have influence on the fluid intelligence. There were the two mechanisms of working memory, storage system and central executive system, associated with fluid intelligence. The storage system is more important and it may mediate the effect of central executive system on fluid intelligence.

1. Introduction

Intelligence has always been one of the core concepts in the field of psychology, and there are endless researches on intelligence. According to Gf–Gc theory [1], intelligence can be divided into two kinds of abilities: fluid intelligence (Gf) and crystallized intelligence (Gc). Gf is the capacity to take care of conceptual issues in novel circumstances, while Gc addresses information and abilities gained through training and involvement with a few areas [2]. Gf has been normally viewed as the most solid and prescient measure for fruitful execution in both instructive and expert settings. Prototypical assignments to gauge Gf are supposed lattice thinking undertakings, for example, Raven's Progressive Matrices, which is perhaps the most as often as possible utilized tests. Gc can be estimated with spelling quizzes or assignments requiring general information. Also, Recently, some researchers have used high-resolution MRIs to comprehensively explore the differences in the brain regions of 740 healthy participants' Gf and Gc. The investigation found that better in Gf was related with cortical extension in areas identified with working memory, attention, and visuo-spatial processing, while Gc was related with more thinner cortex just as higher cortical surface territory in language-related organizations [3].

WM implies a memory framework with restricted capacity that briefly stores and handles current assignments data when individuals perform intellectual tasks. It is considered to be the core of human cognitive activities as comprehension, learning，reasoning and intellectual activities [4]. WM comprises an central executive system(CES)，which is responsible for information processing, coordination, planning and supervision. Besides, it also includes two short-term memory (STM) storage systems, with limited capacity, the‘phonological loop’and the ‘visuospatial sketchpad’, which store acoustic and visuospatial information respectively [5], together with the later proposal of a fourth component, the episodic buffer [6].

2. Background

A large number of studies have found a close relationship between Gf and WM [7–10]. They are related to many mental processes, such as attention control and inhibition, and belong to high-level cognition. However, the conclusions of some of these studies are inconsistent. Different researchers have discovered that the CES and other components of WM are closely related to Gf, but there has been debate concerning the precise contribution of WM specific-components to Gf. Specifically, there are many possible mechanisms for the influence of WM on Gf, such as attention control [11], capacity [12], and similar neural bases [13]. However, the role of working memory on fluid intelligence are unclear.

3. The Role of Working Memory on Fluid Intelligence

Gf can effectively predict an individual's academic or professional success [14]. Therefore, it has always been the focus of researches in the field of cognition. The problems in real life are complex and changeable, and it is far from enough to rely on the original accumulated experience. In this context, experience-independent Gf is particularly important. Therefore, it is very valuable and meaningful to study clearly the psychological and physiological mechanisms of Gf, and to find ways to increase or slow down the decline of Gf with age. The purpose of this review is to explore the role of WM in Gf in terms of mechanisms by summarizing previous studies.

As the strongest single predictor of Gf [15], WM could be fractionated into two components: storage and the CES. Numerous studies have revealed that both the storage components (STM) and the control component (CES) of WM plays important roles on Gf.

3.1. Central Executive System

Some studies have shown that the CES plays a vital role in Gf [16,17]. The main psychological mechanism of this function is the attention control. Attention control（also named executive attention）is an ability to focus on information related to the task in the face of distracting stimuli and interference [18]. Some researchers used the anti-saccade task to investigate the attentional operation of individuals with different WM and found that high WM participants performed better than low ones [19]. The anti-saccade task is a nonverbal visual orientation task. Participants need to maintain their focus in the face of interference when completing the task. Chen et al used structural equation model to explore the relationship among intelligence, attention control and WM [20]. The outcomes indicated that these three latent variables are significantly related to each other(rs = 0.37~1.00). This means that cognitive control is the core function of Gf and may be the cognitive mechanism of the relationship between WM and Gf.

Another important function of attention control is to filter irrelevant information, that is, the filtering ability [21]. The capacity of WM is limited. Facing a large amount of information in a complex environment, a good filtering ability helps to concentrate only limited resources on information related to cognitive tasks, thereby improving people's performance in the tasks. So the filtering ability is a basic component in individuals' almost all cognitive abilities, including Gf [22]. Feldmann-Wüstefeld and Vogel explored the brain mechanism of this ability by changing the number of increasing distractors and the homogeneity of the colors of the target and the distractors [23]. They found distractor items, which increased with increasing distractor loads and distractor heterogeneity, elicited a distractor positivity component in the event-related potential. In addition, although the target caused the contralateral delay activity (CDA) (starting about 300 milliseconds), the distractor caused a continuous positivity contralateral to memory-distractors (CDAp, starting about 400 milliseconds). These results indicate that effective suppression may contribute to good WM performance to a large extent.

3.2. Storage System

On the contrary, other studies have shown that the WM storage is more important [24,25]. Individuals with high WM storage can stably and accurately characterize novel problems and make assumptions, thereby improving the efficiency of problem solving. Cowan et al [26]studied the relationship between WM storage and Gf measured in a simple change detection task proposed by Luck and Vogel [27]. In this task, observers first saw an array of multiple-colored. Then there was a short time delay, and then the observers needed to indicate whether the items in the subsequent test array have changed. It was worth noting that the task in the experiment did not impose any other information that requires additional attention or eliminate stimulus interference, so the results showed that the WM storage could independently predict changes in Gf. Similarly, Chuderski et al [28] used an adjusted n-back assignment to test the amount of variance in reasoning that was accounted for by each of CES and storage with 6 experiments .The results showed that the WM storage accounted for up to 62% of variance in Gf and CES accounted for up to 13%. However, attention control and inhibition were not related to Gf once WM storage was controlled for.

Based on previous researchers, Shipstead et al [29]proposed that multiple mechanisms were needed to explain the individual differences in the relationship between WM storage and Gf (such as primary memory, retrieval from secondary memory, and attention control). They used the structural equation method to explore the cognitive mechanism of WM capacity through the performance of 215 participants (M = 22.31) on complex span, running memory span and visual arrays tasks. The results indicated that the secondary memory was the only factor that directly explains the correlation between WM storage and Gf. Besides, regardless of the working memory task that was used, it is found that primary and secondary memory were fully used to explain the relationship of WM storage to Gf. Any effect that attention control has on novel reasoning is realized through an effect on memory. In other words, the memory storage played a mediating role in the influence of attention control on Gf. Recently, in order to further explore the structures of WM storage and its influence mechanisms on Gf, Vergauwe et al [30] used Bayesian state-trace analysis and based on participants' multitasking performance in the two experiments to prove that WM storage was a single domain-general cognitive resource, not multiple specialized domain-specific ones. In two experiments, participants completed complex span tasks with verbal (aurally-presented non-words) and visuo-spatial (visually-presented spatial locations) memoranda, fully crossed with verbal (rhyme judgment) and visuo-spatial (symmetry judgment) processing tasks, yielding four task combinations. This research further proved that WM storage could fully explain the effect of WM on Gf.

4. Conclusion

In general, WM storage and CES were all found to account for some of the relation. In my opinion, storage systems are more important than CES. The reasons can be attributed to the following two points: 1) Compared with WM storage, there is no direct correlation between CES and Gf; 2) WM storage mediates the effect of CES on Gf.

5. Limitations and Future Direction

So far, the researches on the mechanism of WM and Gf have the following problems: 1) Most of them are correlational studies, lacking proof of causality; 2) The cognitive processes involved in many tasks interact and connect with each other. It is difficult to completely separate these processes when measuring, which also weakens the robustness of the results to a certain extent.

In future research, on the one hand, it is necessary to combine psychological mechanisms with brain mechanisms to further explore the direct or indirect role of attention control in the WM-Gf relationship. In order to further explore the boundary of mechanisms of WM's effect on Gf, many other variables should also be taken into consideration. For example, time constraints, complexity of tasks, age of participants, etc. On the other hand, there is no sufficient evidence to prove the training effects of improving Gf through WM training. Some researchers have found that WM capacity and Gf of students aged 6-7 have been significantly improved in the short and long term after WM training [31]. However, a meta-analysis by Sala and Gobet [32] (m = 41 , k = 393 , N = 2,375) found that the effect of WM training in memory tasks had a small to moderate transfer (near transfer). No transfer effect was found in cognitive tasks such as Gf (distance transfer). In the future, researchers can explore the differences in neuroplasticity by exploring the differences in the psychological mechanisms of WM and Gf among people of different age groups, and make targeted training methods and plans.

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