International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:6, No:6, 2012

Memory and Higher Cognition

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***Abstract*—**Working memory (WM) can be defined as the system which actively holds information in the mind to do tasks in spite of the distraction. Contrary, short-term memory (STM) is a system that represents the capacity for the active storing of information without distraction. There has been accumulating evidence that these types of memory are related to higher cognition (HC). The aim of this study was to verify the relationship between HC and memory (visual STM and WM, auditory STM and WM). 59 primary school children were tested by intelligence test, mathematical tasks (HC) and memory subtests. We have shown that visual but not auditory memory is a significant predictor of higher cognition. The relevance of these results are discussed.

***Keywords*—**higher cognition, long-term memory, short-term memory, working memory

I. Introduction

THERE is increasing evidence of the relationship between memory and higher cognition. However it is not still clear what is the basis of this relationship. The nature and the types of memory have been hotly debated for a long time. Usually, the memory is divided into two main structures. The long-term memory (LTM) can store vast amount of information for a longer time whereas the short-term memory (STM) represents active maintain of some little pieces of information for a shorter time [1]. In psychology, this distinction has a long history dated back to William James [2]. Despite it, some researchers demonstrated existence of a one-store model. But neuropsychological studies confirmed mostly the distinction between STM and LTM [3].

Even more complicated situation concerns the relationship between STM and working memory (WM). Usually three possibilities are assumed. Firstly, WM cannot be removed from the construct of STM. WM and STM share overlapping neurocognitive areas and both of them measure the same ability, i.e.WM and STM are more or less the same constructs [4]–[6].Secondly, the relationship between WM and STM can be explained in terms of superiority and inferiority. Some studies have shown, that STM is a subset of WM [3], [7], [8] Cowan et al. [6], [8] considered STM as a simple storage whereas WM as a storage with attention component. There is also opposite assumption, which believes that WM is a part of STM [9]. Thirdly, there is also evidence, that WM and STM are isolated functions or functions with only a small overlap [10],[11].

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Thus, it is difficult to define WM. Cowan [12] reported that there is no consensus of WM definition in the community of psychologists. WM can be described as a system of holding small amount of information in mind that is easy retrievable [12] or a system that operates via dynamic interaction between memory and executive attention processes [7]. WM is a function which makes possible to maintain task goals in the face of interference [13], [14]. The most important word in WM definitions are “retrievable” and “interference”. WM shares the first word with STM whereas the second word is characteristic only for WM. WM, for us, is the system which actively holds information in the mind to do tasks in spite of the distraction. In the contrary, STM is a system that represents the capacity for active storing of information without any distraction. This hypothesis wants to show that WM and STM are partially overlaid but concurrently unique.

The basal differences between WM, STM and LTM were shown. However, which of them is responsible for the connection with higher cognition is unknown. Many studies highlighted significant correlation between memory and higher cognition [15]–[21]. There is strong evidence that WM correlates with higher cognition more than STM. For example, Daneman and Carpenter [22] found that reading span, which is traditionally considered as a measurement of WM, correlated more highly with several measures of fluid intelligence than did simple word span, which measures STM. In this and other similar studies there is an implicit assumption of separation between WM and STM. In contrast, other studies consider connection between these types of memory. Other discussed type of memory related to higher cognition is LTM. Mogle and cowerkers tested the participants in processing speed, STM, WM, LTM and fluid intelligence. It was shown that LTM component was the strongest predictor of fluid intelligence. In contrast, WM did not predict significantly the variability in fluid intelligence after accounting for the variance in fluid intelligence associated with the LTM [19]. But there is also evidence, that the LTM processes are not the only ones that cause the relationship between memory and higher cognition. Unsworth and his colleges [21] also considered STM processes to be important in the relationship between memory and higher cognition. They have shown that individual differences in working memory capacity (WMC) and subsequently in fluid intelligence are caused by two memory processes – the active maintenance (STM) and the cue-dependent search (LTM). They came out of the idea that STM capacity is approximately four items [23]. When more than four items are presented, the items currently within STM are displaced and consequently must be recalled from LTM by means of the cue-dependent search process [21].

Thus, this group of authors considered the STM processes important in relationship between memory and higher cognition. These conclusions were confirmed by Shelton and coworkers [18] who investigated the relationship between processing speed, WM, LTM, STM, and fluid intelligence. They demonstrated that all constructs are significantly correlated with fluid intelligence. But only WM processes were significant in unique variance of fluid intelligence. These findings suggest that the combination of maintenance (STM) and retrieval processes (LTM) presented in WM tests makes them special in their prediction of higher cognition. It is possible therefore to conclude that the uniqueness of WM resides in the special position between STM and LTM (Fig. 1).

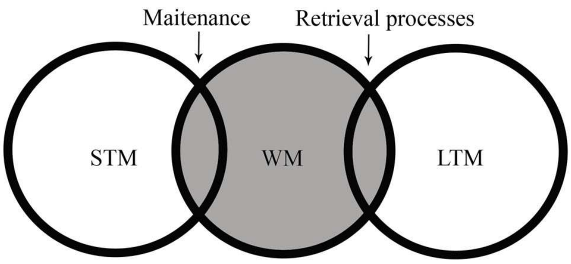

Fig. 1 Simplified memory system

Both STM and WM are considered to be comprised by visual and auditory components. The most cited scheme is the scheme of Baddeley [24]. They developed multi-component model of WM, which was based on Atkinson and Shiffrin modal model [26]. This original Baddeley model was extended several times and its last version is given in Fig. 2.

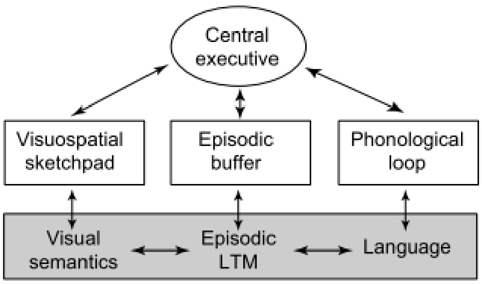

Fig. 2 Working memory model of Baddeley (2000) [25]

Baddeley´s model contents two stores – auditory (phonological loop) and visual (visuospatial sketchpad). The newest part of this model is the episodic buffer [24]. Two stores actively maintain information and the central executive is responsible for the focus attention to relevant information and for the coordination of cognitive processes which occur simultaneously. The fourth part, the episodic buffer, was added because of some facts which could not be explained by original model (for example, how verbal and spatial types could be combined, how abstract and other modality information could be remembered). Thus, the role of the new component is holding representations that integrate phonological, visual, and spatial information and information from other modalities. Concerning the differences between visual and auditory memory Baddeley's model advocates the differences between these memory types. But there is one trouble. In many visual memory tasks the participants are asked to remember list of some visual stimulus. This stimulus can be coded be visuospatial sketchpad but also by phonologoical loop. For example, the participants are asked to remember a series of pictures which are presented in one-second intervals. Participants get visual stimuli but also can get auditory ones (because of silent or laud repeating). In contrast to Baddeley's model, Cowan [12] supposed that phonological and visuospatil stores are over-specified. He cited the experiment of Conrad (1964) which demonstrated the acustic confusion in the case of remembering printing letters [27]. Newer studies offered similar results [28]. The acustic confusion effect was shown not only in case of remembering English written words but also in remembering logographic Japanese Kanji. Phonologically similar words caused more confusion than visually similar words in both languages. Based on these findings, Cowan [8] presented a new model of WM. In his model (Fig. 3), the visual and the phonological stores are considered instances of the temporary activation of LTM. The idea of the separated stores is replaced by the idea called the focus of attention.

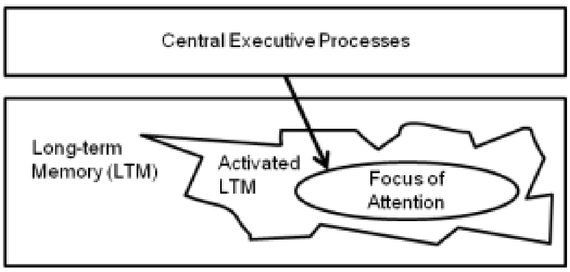

Fig. 3 Working memory model of Cowan (1988) [8]

In summary, there is a relative agreement that memory is connected with higher cognition. Some inconsistencies are in finding of memory types which are responsible for this relationship. So, the aim of the present paper was to identify the nature of the relationship among memory and intelligence and to specify the link between visual and auditory stores.

II. Methods

A. Participants

Sixty children were recruited from primary schools (22 females, 38 males; mean age = 11.2 ± 0.87). There were no significant between-group age differences and between-group gender differences. Similarly no gender differences were found in intelligence and mathematical tasks (Fig. 4).

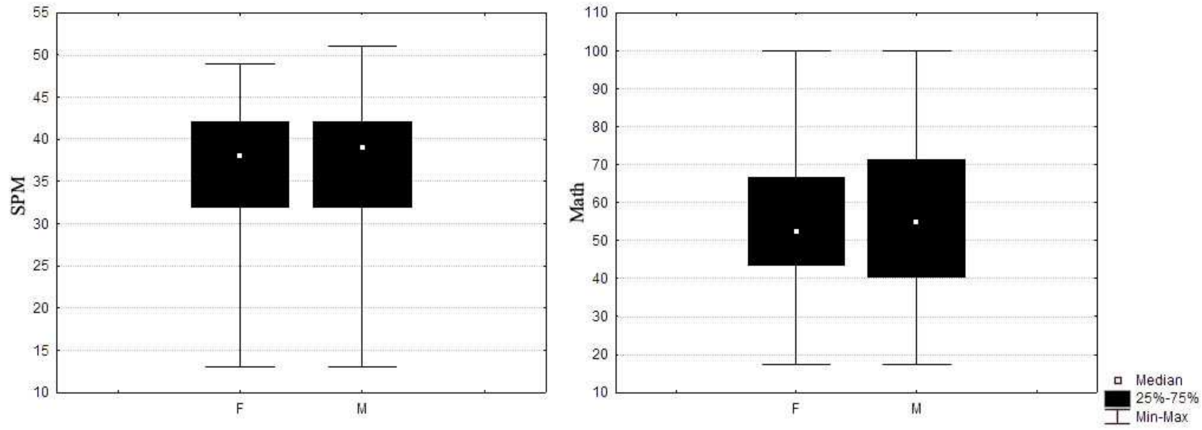

Fig. 4 The results of intelligence test (standard progressive matrices, SPM) and mathematical tasks in females (F) and males (M)

B. Measures

Participants completed an intelligence test and mathematical tasks as well as five tasks measuring each of the following cognitive constructs: visual WM, visual STM, auditory WM, auditory STM and LTM. Fluid intelligence was measured by *The Raven's Standard Progressive Matrices* (SPM) [29]. Mathematical ability was measured by didactic tasks according to children´s classes. Visual WM was measured by *Bead Memory* from Stanford-Binet Intelligence Scale [30]. The participant was presented with pictures of a bead design and asked to replicate it from memory. This subtest was not ordinary associated with WM, but according to WM definition presented above was convenient. The distraction can be in other modality. In the case of *Bead Memory* the distraction is created by searching for appropriate bead in a box. Visual STM was measured by *Memory for Objects* from Stanford-Binet Intelligence Scale [30]. The participant is presented with sequences of single pictures and subsequently is challenged to show pictures in serial order. Auditory WM was measured by *backward Digit Span* from Stanford-Binet Intelligence Scale [31]. Auditory STM was measured by *forward Digit Span* from Stanford-Binet Intelligence Scale [30]. LTM was measured by *Memory for Names* from Woodcock-Johnson Inteligence Test [31]. It is a test with supervised learning. Participants are presented with pictures of aliens and with their unusual names and ask to memorize them. Subsequently they are asked to assign alien's name to the picture.

C. Analyses

The normal distribution was not proved according to Shapiro-Wilk W test of normality (not shown) and therefore nonparametric methods were used. The differences between male and female were evaluated using Mann-Whitney U test.. The correlations between memory tests and higher cognition were examined by Spearman's rank correlation coefficient.

A value of $P < 0.05$ was considered significant. Statistical analyses were performed with Statistica 6.1 software (StatSoft, Tulsa, OK).

III. Results

The goal of the analyses was to examine the relationships among the LTM, visual WM and STM, auditory WM and STM, and fluid intelligence. The descriptive statistics are shown in Table 1. Only one variable revealed a single value greater than ±3.5 standard deviation above or below the mean of the respective variable. The results were not changed if this value was replaced by the mean ±3.5 standard deviation. Thus, the raw values were used in the following analyses.

The values of skewness and kurtosis of all variables reached generally accepted values. However most of the values were not normally distributed (Shapiro-Wilk W test), therefore nonparametric methods were used for further analyses. To identify the relationship among the studied variables correlation analysis was performed. The results are summarized in Table 2. The results show that fluid intelligence (SPM) significantly correlates with visual type of memory (*Bead Memory and Memory for Objects*) and with LTM (*Memory for Names*), however there was not find any correlation between fluid intelligence and auditory memory (both type of *Digit Span*). The strongest correlation with fluid intelligence was found in case of *Bead Memory* (visual WM), followed by *Memory for Objects* (visual STM) and *Memory for Names* (LTM). Weak correlation was found in case of *backward Digit Span* (auditory WM) and none in case of *forward Digit Span* (auditory STM). In most cases of short memory types (WM, STM) the strongest correlation was found between memory of the same modality (*Beat Memory* and *Memory for Objects*, *forward* and *backward Digit Span*) and weaker between memory of the same type (*backward Digit Span* and *Beat Memory*).

TABLE I
DESCRIPTIVE STATISTICS FOR ALL MEASURES

Task	Mean	Minimum	Maximum	SD	Skew	Kurtosis
SPM	36.85	13.00	51.00	8.53	-0.71	0.56
Mathematical tasks	56.29	17.39	100.00	21.91	0.17	-0.59
Bead Memory	23.51	10.00	35.00	4.45	-0.36	1.22
Digit Span forw.	5.73	3.00	9.00	1.58	0.41	-0.20
Digit Span Backw.	3.92	2.00	9.00	1.49	0.80	1.06
Memory for Names	52.69	24.00	71.00	12.65	-0.53	-0.60
Memory for Objects	6.86	4.00	9.00	1.21	0.09	-0.40

N = 59 for all measures. Raw scores were used for all tests except mathematical tasks. Mathematical scores were percentage of fulfilment of the test because of the different tests for different age (100% get children with higher raw scores in every age group).

TABLE II
CORRELATION MATRIX AMONG ALL COGNITIVE TASKS

	1	*2*	*3*	*4*	*5*	*6*	*7*
1. SPM	1.00						
2. Mathematical tasks	.45*	1.00					
3. Bead Memory	.54*	.42*	1.00				
4. Digit Span Forw.	.05	.13	.18	1.00			
5. Digit Span Backw.	.13	.39*	.40*	.46*	1.00		
6. Memory for Names	.34*	.45*	.34*	.19	.49*	1.00	
7. Memory for Objects	.42*	.51*	.42*	.01	.22*	.42*	1.00

*p < .05.

TABLE III
CORRELATIONS AMONG ALL MEMORY INDEXES AND LTM, SPM AND MATHEMATICAL TASKS

	1	2	3	4	5	6	7
1. WM	1,00						
2. STM	.50*	1,00					
3. Visual Memory	.91*	.53*	1,00				
4. Auditory memory	.54*	.76*	.32*	1,00			
5. LTM	.45*	.39*	.40*	.41*	1,00		
6. SPM	.50*	.30*	.59*	.12	.34*	1,00	
7. Mathematical tasks	.45*	.43*	.51*	.31*	.45*	.45*	1,00

*p < .05.

The strongest correlation of LTM (*Memory for Names*) was found with *backward Digit Span*. In addition, there was also strong correlation between LTM and mathematical ability.

To verify the relationship between WM and STM and between visual and auditory memory the indexes of WM (counted as a sum of *Bead Memory* score and *forward Digit Span*), STM (counted as a sum of *Memory for Names* and *backward Digit Span*), visual memory (counted as a sum of *Bead Memory* and *Memory for Name*) and auditory memory (counted as a sum of *forward* and *backward Digit Span*) were introduced and correlations between these indexes and LTM, mathematical ability and SPM were calculated, respectively (Table III).

All indexes except index of auditory memory correlated significantly with SPM. In contrast, the mathematical ability correlated significantly with all memory types. Correlation between WM and STM was higher than correlation between visual memory and auditory memory.

Based on the correlation data we have proposed a memory-intelligence model (Fig. 5) that demonstrates unique position of WM in the link between memory and intelligence. WM correlated with all variables more strongly than correlated STM vs, LTM, STM vs. SPM, and LTM vs. SPM.

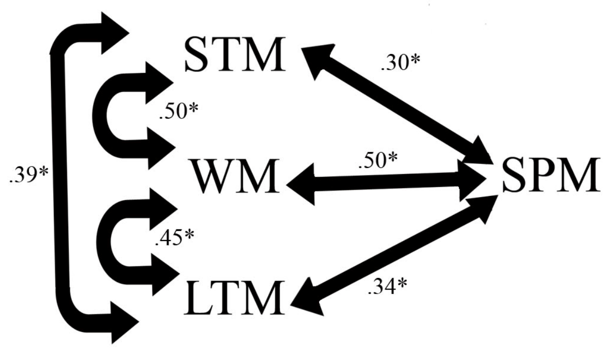

Fig. 5 The model of memory-intelligence

IV. Discussion

The aim of the current study was to investigate the relationship between memory and higher cognition in context of different memory types. Our data show that STM and WM are overlapping constructs as published by others [3], [7], [8], support previous findings that memory is associated with higher cognition and demonstrate a stronger correlation between WM and intelligence than between STM and intelligence [21, [23]. The memory-intelligence model (Fig. 5) implicates that WM is predominantly responsible for relationship between memory and intelligence and our data justify WM cognitive training for improvement of intelligence [32], [33]. The major novel result of this study is demonstration that visual but not auditory memory is a significant predictor of fluid intelligence. The question is therefore whether visual and auditory memory can be separated and their contributions to higher cognition are completely different. As shown in Table 3 WM and STM correlate more strongly than visual and auditory memory. However, in respect with previous studies [12], [27], [28] we assume that division memory into visual and auditory branch need not be self-evident. These presumptions were confirmed by our own experience with individual testing. To remember pictures many children assisted themselves by loudly repeating the visual stimuli. It is possible therefore, that some visual memory tests do not measure only visual memory. In case of auditory tests the situation is not inverse. Although the participants can also assist themselves by visual imagination it is impossible for them to create a real stimulus. It seems therefore that visual memory might be superior and that the relationship between visual and auditory memory might be analogous to the relationship between WM and STM [3], [7], [8]. The relationship between visual and auditory memory could be depicted as shown in Fig. 6.

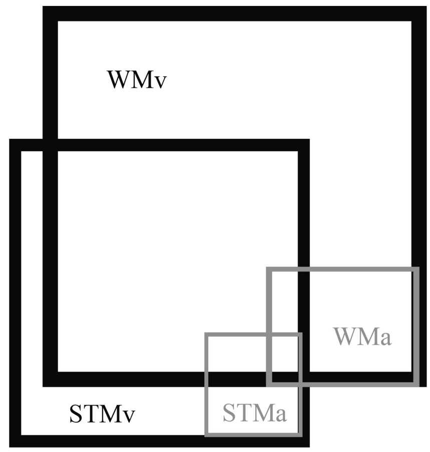

Fig. 6 Simplified scheme of visual WM (WMv), visual STM (STMv), auditory WM (WMa), and auditory STM (STMa)

Significant relationship between LTM (*Memory for Names*) and *backward Digit Span* can be explained by Cowan’s idea that stores are instances of the temporary activation of LTM [23], [32]. However the correlation between *forward Digit Span* and LTM was absent in our study. This might reflect the fact that *backward Digit Span* is more dependent on LTM. In respect to Cowan’s magical number 4 (capacity of short term memory) [23] our children had to store two items into LTM in *forward Digit Span* on average (mean 5,7 items; 4 items in STM/WM, 2 items in LTM). In contrast, *backward Digit Span* requires to store all items in LTM because WMC has to be able to invert the number (mean 3,9 items; 4 items in LTM). Thus the data are in line with the argument WM is special in the relation with higher cognition due to its responsibility for interaction between the active maintenance of items in STM and the controlled search in LTM [23].

The relationship between fluid intelligence and mathematical ability is generally accepted. Nevertheless in our study mathematical ability correlated significantly also with all memory indexes and all memory tasks with the exception of *forward Digit Span*. In contrast, fluid intelligence did not correlate with index of auditory memory. These findings implicate that there is something unique in the relationship between memory and mathematical ability; something what can not be explain only by the relationship between mathematical ability and intelligence.

In summary, the present study confirmed the relationship between memory and intelligence, particularly the responsibility of WM for relationship between memory and higher cognition. We have shown that visual but not auditory memory is a significant predictor of intelligence. This finding may not mean the distinction between phonological and visuospatial store but the superiority of visual memory. However, further studies will be required to prove this superiority.

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