Working Memory Span Research for Geometric Material Processing

Lubov Cheremoshkina[1], Maria Dymnikowa[2]

Psychology Department, Moscow State Pedagogical University
ul. Malaya Pirogovskaya 1/1, 119991, Moscow, Russia
LVCH2007[at]yandex.ru[1], dmwl[at]bk.ru[2]

ABSTRACT — ***Article presents working memory span specifics in empirical background and the approach of patterns of visual geometric information processing research by using L. Cheremoshkina mnemonic abilities' diagnostic method in experimental studies' series on over 1500 young people from primary school until student's level. It allows studying the mechanisms of visual geometric abstractive material processing in the progress from short-term memory storage to long-term memory storage, which results of mnemonic activity's experimental research are described.***

Keywords — working memory span, short-term memory, long-term memory, methods of geometric material processing.

1. WORKING MEMORY SPAN BACKGROUND

In 1974 Baddeley and Hitch, developing the ideas of Atkinson and Shiffrin, defined working memory as a component of long-term memory storage with including short-term memory storage, which contains only the information from long-term memory in active processing. In contemporary cognitive psychology, working memory is considered in accordance with the following characteristics. It differs not only by the length of storage, but also by information processing needed for performing a wide range of complex cognitive tasks (Aben, Stapert, Blokland, 2012). It involves selection, initiation and termination of such information processing as encoding and extracting data (Desimone, 1996). It is a necessary component of attention monitoring processes (Awh, Jonides, 2001). It is an important function for decision-making, a kind of cognitive buffer in the process of implementing executive functions (Baddeley, Hitch, 1974). It has a neuropsychological basis, consisting in the activation of the parietal and prefrontal cortex areas, regardless of the type of sensory modality of the perceived information, with the presence of dopamine as the central neurotransmitter of this cognitive function (Klingberg, 1998; Malenka, Nestler, Hyman, 2009; Olesen, Westerberg, Klingberg, 2004). It should be noted that in the middle of the 20th century, laws of working (operative) memory functioning were described in Russian psychology, which was designated as something between short-term storage and long-term storage. It was characterized by the results of the operator activity psychological analysis in human-machine systems. Working (operative) memory was marked by the retention function of information necessary for the implementation of current activities (Dushkow, Smirnow, Korolew, 2005).

In the last decades a considerable number of hypotheses, approaches and experimental data on the mechanisms of working memory functioning have been accumulated. A significant part of these studies is devoted to determining working memory span. Most researchers tend to 3-4 objects as an indicator of the working memory span average amount (Cleeremans, McClelland, 1991). Cowan has limited the working memory span for the focus of attention on stimuli which are directly stored and organized by long-term memory activation (Chase, Simon, 1973). Subsequent studies by Cowan and Saults (Saults, Cowan, 2007) of simultaneous memorization of sensory auditory and visual material confirmed these conjectures. The results of using the dual receptor modality tasks confirmed that the number of auditory and visual elements stored together was within 3-4 elements. The obtained data certify to the existence of a single central capacity for memorizing and storing bimodal and unimodal types of information. Halford, Maybery, and Bain (Halford, Mayberry, Bain, 1988; McErlee, 1998; Oberauer, 2001) revealed empirically that interference effect for memorizing of the four elements is not manifested. According to the definition of Cowan (Cowan, 1995), the memory traces most accessible to us, those which are recalling and reproduced at the highest speed, are located in the focus of attention for a maximum of 3 to 4 elements. Oberauer and McErlee (Oberauer, 2002) in the working memory span experimental verification revealed that in tasks with simultaneous mental processing of all memorized stimuli (in the performance of logical, mental operations on memorized material by using the example of an account, spatial transformations, or letter changes), there can be processing only one memorable stimulus in active attention. With that the remaining incentives are not amenable to forget. It should be emphasized that the higher working memory loads the lower possibility of logical processing of its contents (Barrouillet, Bernardin, Camos, 2004).

Empirical studies by Cowan and Oberauer, McErlee (McErlee, 2001) revealed that the information is processed sequentially, despite the fact that up to 3 elements can be located outside the focus of attention, which are not forgotten and retained in involuntary memory during redirecting the focus of attention from one operation to another. For the present time a significant number of confirmations of the working memory span about four units have been accumulated: 1) - memory research in conditions of arbitrary and involuntary memorization (Cowan, Nugent, Elliot, Ponomarev, Saults, 1999; Jones, Farrand, Stuart, Morris, 1995; Sperling, 1960); 2) - experiments with jamming presence for information redirecting from short-term storage to long-term storage and with limited conditions for using long-term memory to perform the mnemonic task (Glanzer, Razel, 1974; Pollack, Johnson, Knaff, 1959; Simon, 1974; Waugh, Norman, 1965); 3) - study of proactive and retroactive interference mechanisms (Henderson, 1972); 4) - study of effective reproduction cases (Broadbent, 1975); 5) - study of memorizing and reproducing speed factors (Mandler, Shebo, 1982; Pylyshyn, Burkell, Fisher, Sears, Schmidt, Trick, 1994; Trick, Pylyshyn, 1993); 6) - study of direct and delayed reproduction's volume (Cowan, 1999; Ericsson, Chase, Faloon, 1980; Graesser, Mandler, 1978; Ryan, 1969; Wickelgren, 1964); 7) - experiments with taking into account the novelty effects of remembered and reproduced information (Watkins, 1974); 8) - study of span influence of short-term memory and working memory on the cognitive task productivity (Fisher, 1984; Logan, 1988; Logan, Klapp, 1991); 9) - studies oriented on mathematical modeling of working memory parameters (Halford, Wilson, Phillips, 1998; Kintsch, Dijk, 1978; Raaijmakers, Shiffrin, 1981). These studies of mnemonic processes allow certifying in favor of specificity of material processing mechanisms in working memory.

In the beginning of 20th century, this phenomenon was described in the dominant theory by Russian physiologist Uhtomskij (Uhtomskij, 2002). It should be noted that this theory brought researchers closer to a systematic understanding of the human's physiological and psychological manifestations. The presence of a dominant changes in the activity's coordination of brain's different parts, functionally related to the strongest focus of excitation. Dominant excitation by the negative induction's rule causes inhibition of other nerve centers with a difference between lower and higher dominants. Lower dominants wear physiological nature and higher dominants arise in the cerebral cortex and constitute the physiological basis of attention and objective thinking acts. Dominant in psychological definition is the behavior's motivational potential. The mechanism of dominant explains a wide range of attention's psychological acts - its focusing on certain objects, concentration and selectivity. Subsequent psychophysiological and modern neurophysiological studies certify evidence in favor of working memory specificity as an intermediate stage between short-term memory storage and long-term memory storage (Cirkin, Truhina, 2001; Dushkow, Smirnow, Korolew, 2005).

2. GEOMETRIC MATERIAL PROCESSING RESEARCH NOTE

Cheremoshkina L.V. (Cheremoshkina, 1988; 2009) worked out the diagnostic method of mnemonic abilities, based on a visual geometric abstractive material that allows investigating the productivity and qualitative identity of the human's memory of different age groups. This method concerns 10 cards with images of abstractive figures composed on straight intersecting lines with increasing complexity (amount of lines from 3 to 7, including past principle of Miller's number of memory span average around 7 items). Time of each card's presentation follows: from 1st to 10th presentation – 1 second, from 11th to 20th – 2 seconds, from 21th to 30th – 3 seconds etc. Amount of presentations depends on the correct redrawing of the memorizing abstractive geometric lines' scheme, so until the first correct reproduction of the figure. Each reproduction of the subjects is fixed on the selected paper sheet. Short time of material's presentation allows deploying mnemonic activity, in other words to investigate the micro-genesis of the mnemonic process of the unfamiliar material perception of its memorization and correct reproduction. Since 1986 several dozen series of independent studies with using the mnemonic abilities' diagnostic method have been conducted involving people from primary school children to students with the total sample size over 1500 subjects. On the basis of this method, Cheremoshkina L. V. (Cheremoshkina, 1988; 2009) revealed the mnemonic abilities' classification during analysis of the geometric material processing. Memory is considered as a multi-level and developing system of information organization for the purpose of the human's future activity. The process of representing the information in human's memory is accomplished through mnemonic activity's instruments, i.e. mnemonic abilities, which are tools for encoding and decoding information in order to memorize, preserve and reproduce it. Mnemonic abilities as sources of memorization and reproduction are realized by different levels of its mechanisms. They are implemented by mechanisms of multilevel processing: functional, operational, regulation. The basic level is formed by functional mechanisms or elementary mnemonic abilities (i.e. first level of mnemonic abilities' development classification). Its productivity in pure form is manifested in the power of imprinting with mechanical repeating when needed. Functional mechanisms as genotype and innate abilities due to the foundation are trained to the extent of any involvement of the analyzing system, also are conditioned congenitally and by genotype. It concern natural spontaneous memorizing without needed working out and processing out the memorized material (diagnostic cards with 3 and 4 lines).

Operational mechanisms (i.e. second level of mnemonic abilities' development classification) are ways of processing information, in analysis and interpretation procedures. They are formed up by the brain structures' maturation and human's brain activity development. They are due to the formation of the most complex mental activities aimed at organizing a holistic cognitive act. It forms up mnemonic activities as background of operational mechanisms. We revealed them during empirical studies on working memorizing with visual geometric material processing. They include such procedures as re-encoding, analogy, schematization, structuring, reconstruction, grouping, stronghold point, association, systematization, serial organization, classification. These methods of memorizing and reproducing the material are of various complexity mechanisms, which are very adaptive with respect to perceived information and the conditions of an intellectual task. Totally mnemonic techniques allow the subject to expand the possibilities of memorizing material of different volumes, of varying complexity, and under different conditions of presentation. They are based on a certain maturity of brain structures or functional systems. During the cognitive intelligence developing period the mnemonic techniques - i.e. operational mechanisms - are becoming more and more manageable due to goal-setting operations, decision making, planning, forecasting, improved orientation in the material, monitoring, evaluation, correction of the mnemonic process and anticipation of the parameters of the future result. The aggregate interaction of these operations forms the background of regulation mechanisms (i.e. third level of mnemonic abilities' development classification), which form up the system interaction of control, assessment, anticipatory and other functions, the manifestation of which is due to volitional, motivational and emotional processes. This interaction is specified for working or activity and includes conscious planned meta-regulation of memory processing, i.e. mnemonic plan. The mnemonic abilities' diagnostic method makes it possible to isolate and extract the productivity and qualitative specificity of each mnemonic activity mechanism, in other words, the effectiveness and uniqueness of functional, operational, and regulation mechanisms of concrete human's memory. It seems to us that the stage of memorizing with the functional mechanisms' support corresponds to the stage of spontaneous natural material processing in working memory, and the amount of stored and correctly reproduced material based on these stage's results can be considered as the working memory span's indicator. Operational mechanisms are almost unconsciously and mostly non-needed for memorizing the material at this memory processing level. Treatment, if takes place, generally occurs within the perception's framework.

As the human immerses in the mnemonic task's solution, in connection with the difficulties of memorizing or complicating the memorized material, the memorizing processing is including operational and regulation mechanisms, i.e. techniques of grouping, the allocation of a support point with the involvement of associations that are realized within the perceptually representative level of the mental processes' functioning. Additionally in those situations when conscious material processing of visual abstract geometric material turns on, then schematization and structuring are applied. In some cases, during the process of promoting memorization from the first to third figures, there are observed tendencies in the searching for analogies with the previous figures, as well as signs of a mnemonic plan for memorizing processing regulation. We revealed that the period of working memorizing in mnemonic abilities' diagnostic method processing lasted from one sec up to a minute, depending on the degree of effectiveness and the level of human's memory development. The criterion for working memory period's extracting is observed in the indicators of a repeated experiment in which the human is asked to recall and draw a figure remembered some time ago (without additional stimulus exposure). In those cases, when human is coping with the task, we can talk about the transition of the material to long-term memory storage. Otherwise, the information was in short-term memory storage with subsequent forgetting in delayed reproduction or material memorized earlier.

It should be emphasized that the transferring information process from working memory to long-term memory storage is mainly due to the presence of regulation mechanisms and its developmental level. These mechanisms of mnemonic activity do correspond to the metacognition's level and do characterize the high level of both verbal and nonverbal intelligence development. In mnemonic abilities' diagnostic method each figure, besides the lines, contains their intersections and is characterized by the orientation on the flat surface, so memorizing complex abstractive geometric figures describe the intelligence's indicator. To summarize, almost all people aged 7 to 80 years memorized immediately grouped lines in two crosses (2+2) or crossed out letter "A" (3+1). This means that memorizing unit in working memory span can be understood not only by a single line or by a group of lines (4 or 2), but also for the storage unit, as signs of the figure's orientation on the flat surface (minimal 1). Diagnosed people reported that after combining the lines (2 + 2 or 3 + 1) they focused their attention on the sloped line. This leads to a reduction of the intersections' number (from 6 to 4 or 5), the image of which must be controlled at each repetition. Therefore, according to our empirical working memorizing data, after the lines' grouping, with using operation and regulation mechanisms during memorizing process, the memory span for immediate memorizing of visual abstractive unfamiliar geometric material, based on the crossed lines, can be located on the average of 6 - 7 units as lines' intersections.

3. CONCLUSION

Memory studies by using mnemonic abilities' diagnostic method allow observing effective, procedural, and individual characteristics of different human's memory mechanisms levels during immediate memorizing processing of unknown visual abstractive geometric material. Collision with the problem of the inability to quickly and correctly reproduce an abstractive geometric figure made on crossed lines on a flat surface causes the human to find out and to look for ways to memorize it. The period before the conscious and independent memorizing, with the involvement of some operational and functional mechanisms' techniques (what belongs to working memory memorizing with including long-term memory storage space), can be defined as working memorizing level in short-term memory storage space, which is characterized by mechanisms for processing material within the perceptive function and natural spontaneous memorizing with possible unconscious repeating use. The results of many years serial empirical memory studies revealed, that the speed of correct working memorizing in 1 second is conditioned by the high productivity of working memorizing processes located in short-term memory storage (quite easy material), while difficulty with working memorizing in 60 seconds or longer depends on working memory span limitations (quite difficult material), so working memorizing has different manifestations. The majority of age-varying humans demonstrate diverse tendencies in unknown visual abstract geometric material processing during working memorizing in the transition of information from short-term memory storage to long-term memory storage, where working memory is the part of its' both backgrounds. It is characterized on short-term level by natural spontaneous material processing, while on long-term level by using (generally unconscious) methods of information's organizing, during the direct meta-regulation of the memorizing process.

4. REFERENCES

[1] Aben, B., Stapert, S., Blokland, A. (2012). About the distinction between working memory and short-term memory. *Cognition*, vol. 3, p. 301.
[2] Awh, E., Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences*, March 1, 5 (3), p. 119-126.
[3] Baddeley, A. D., Hitch, G. J. (1974). Working Memory. In: G. A. Bower (ed.). *The Psychology of Learning and Motivation: Advances in Research and Theory.* New York. Academic Press. p. 47-90.
[4] Barrouillet, P., Bernardin, S., Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology. General* 133 (1), p. 83-100.
[5] Broadbent, D. E. (1975). The magic number seven after fifteen years. // *Studies in long- term memory,* ed. A. Kennedy, A. Wilkes. Oxford, England, Wiley. p. 3-18.
[6] Cheremoshkina, L. V. (1988). *Diagnosis of mnemonic abilities of school-children aged 10-12.* PHD dissertation for psychological sciences. Leningrad, LGU. [original title: Diagnostika mnemiceskih sposobnostej shkolnikow 10-12 let. Dis. kand. psih. nauk. Leningrad, LGU.]
[7] Cheremoshkina, L. V. (2009). *Psychology of memory.* Moscow, ed. Aspect press. 320 p. [original title: Psihologia pamiati. Moskwa, izd. Aspekt press, 320 s.]
[8] Chase, W., Simon, H. A. (1973). The mind eye's in chess. In: *Visual information processing,* ed. by W. G. Chase. New York, Academic Press. p. 215-281.
[9] Cirkin, W. I., Truhina, S. I. (2001). *Physiological basis of human's psychological activity and behavior.* Moscow, ed. Medical book. 524 p. [original title: Fiziologiceskie osnowy psihiceskoj dejatelnosti i powedenia celoweka. Moskwa, izd. Medicinskaja kniga. 524 s.]
[10] Cleeremans, A., McClelland, J. L. (1991). Learning the structure of event sequences. *Journal of Experimental Psychology: General* 120, p. 235-253.
[11] Cowan, N. (1995). *Attention and memory: an integrated framework.* Oxford Psychology Series, book 26. ed. Oxford University Press. 344 p.
[12] Cowan, N. (1999). An embedded – processes model of working memory. In: *Models of working memory: Mechanisms of active maintenance and executive control.* ed. A. Miyake, P. Shah. Cambridge, Cambridge University Press. p. 62-101.
[13] Cowan, N., Nugent, L. D., Elliot, E. M., Ponomarev, I., Saults, J. S. (1999). The role of attention in the development of short-term memory: Age differences in the verbal span of apprehension. *Child development* 70, p. 1082-1097.
[14] Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proceedings of the National Academy of Sciences of the United States of America*, 93, p. 13494-13499.
[15] Dushkow, B. A., Smirnow, B. A., Korolew, A. W. (2005). *Psychology of work, professional, informational and organizational activity. Dictionary* \working memory\, 3rd ed. Moscow. Academic project. Gaudeadamus. p.360-362. [original title: Psihologia truda, professionalnoj, informacionnoj i organizacionnoj dejatelnosti. Slowar \operatiwnaja pamiat\, 3-e izd. Moskwa, Akademiceskij proekt. Gaudeadamus. str.360-362.]
[16] Ericsson, K. A., Chase, W. G., Faloon, S. (1980). Acquisition of a memory skill. *Science* 208, p. 1181-1182.

[17] Fisher, D. L. (1984). Central capacity limits in consistent mapping, visual search tasks: Four channels or more? *Cognitive Psychology* 16, p. 449-484.
[18] Glanzer, M., Razel, M. (1974). The size of the unit in short-term storage. *Journal of Verbal Learning and Verbal Behavior* 13, p.114-131.
[19] Graesser, I. A., Mandler, G. (1978). Limited processing capacity constrains the storage of unrelated sets of words and retrieval from natural categories. *Journal of Experimental Psychology: Human Learning and Memory* 4, p.86-100.
[20] Halford, G. S., Mayberry, M. T., Bain, J. D. (1988). Set-size effects in primary memory: An age-related capacity limitation? *Memory and Cognition* 16 (5), p. 480-487.
[21] Halford, G. S., Wilson, W. H., Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences* 21, p. 723-802.
[22] Henderson, L. (1972). Spatial and verbal codes and the capacity of STM. *Quarterly Journal of Experimental Psychology* 24, p. 485-495.
[23] Jones, D., Farrand, P., Stuart, G., Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21, p. 1008-1018.
[24] Kintsch, W., Dijk, T. A. V. (1978). Toward a model of text comprehension and production. *Psychological Review* 85, p. 363-394.
[25] Klingberg, T. (1998). Concurrent performance of two working memory tasks: potential mechanisms of interference. *Cerebral Cortex*, 8, p. 593-601.
[26] Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review* 95, p. 492-527.
[27] Logan, G. D., Klapp, S. T. (1991). Automatizing alphabet arithmetic: I. Is extended practice necessary to produce automaticity? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 17, p. 179-195.
[28] Malenka, R. C., Nestler, E. J., Hyman, S. E. (2009). Higher Cognitive Function and Behavioral Control. In: *Molecular Neuropharmacology: A Foundation for Clinical Neuroscience* (2nd ed.). A. Sydor, R. Y. Brown. New York. McGraw-Hill Medical. p. 313-321.
[29] Mandler, G., Shebo, B. J. (1982). Subitizing: An analysis of its component processes. *Journal of Experimental Psychology: General* 111, p. 1-22.
[30] McErlee, B. (1998). Attended and non-attended states in working memory: Accessing categorized structures. *Journal of Memory and Language*, 38, p. 225-252.
[31] McErlee, B. (2001). Working memory and focal attention. *Journal of Experimental Psychology: Learning, Memory and Cognition* 27, p. 817-835.
[32] Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging study with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory and Cognition* 27, 4, p. 948-957.
[33] Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 28 (3), p. 411-421.
[34] Olesen, P., Westerberg, H., Klingberg, T. (2004). Increased prefrontal and parietal brain activity after training of working memory. *Nature Neuroscience*, 7, p. 75-79.
[35] Pollack, I., Johnson, I. B., Knaff, P. R. (1959). Running memory span. *Journal of Experimental Psychology* 57, p. 137-146.
[36] Pylyshyn, Z., Burkell, J., Fisher, B., Sears, C., Schmidt, W., Trick, L. (1994). Multiple parallel access in visual attention. *Canadian Journal of Experimental Psychology* 48, p. 260-283.
[37] Raaijmakers, J. G. W., Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review* 88, p. 93-134.
[38] Ryan, J. (1969). Grouping and short-term memory: Different means and patterns of groups. *Quarterly Journal of Experimental Psychology* 21, p. 137-147.
[39] Saults, J. S., Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and auditory arrays in working memory. *Journal of Experimental Psychology: General* 136 (4), p. 663-684.
[40] Simon, H. A. (1974). How big is a chunk? *Science* 183, p. 482-488.
[41] Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs* 74, No. 498.
[42]. Trick, L. M., Pylyshyn, Z. W. (1993). What enumeration studies can show us about spatial attention: Evidence for limited capacity preattentive processing. *Journal of Experimental Psychology: Human Perception and Performance* 19, p. 331-351.
[43] Uhtomskij, A. A. (2002). *Dominante. Essays of different ages. 1887-1939*. Saint-Petersbued. ed. Piter. 448 p. [original title: Dominanta. Statji raznyh let. 1887-1939. Cankt-Peterburg. izd. Piter. 448 s.]
[44] Watkins, M. J. (1974). Concept and measurement of primary memory. *Psychological Bulletin* 81, p. 695-711.
[45] Waugh, N. C., Norman, D. A. (1965). Primary memory. *Psychological Review* 72, p. 89-104.
[46] Wickelgren, W. A. (1964). Size of rehearsal group and short-term memory. *Journal of Experimental Psychology* 68, p. 413-419.