We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Aging Associated Specificity in Training Visual Short-Term Memory

Olga Razumnikova and Vladislav Kagan

Abstract

There are numerous data in existence, the computerized cognitive training programs (CCTP) maintain or improve the plasticity of the neural networks in the brain. It is known as well that CCTP reduces the probability of cognitive dysfunctions associated with aging. In the chapter, the age-associated specificity in the temporal dynamics of changes in the visuospatial short-term memory (VSWM, also called visuospatial working memory) is presented. VSWM has been analyzed as there are evidence for age-related decline in visuospatial memory associated with hippocampus atrophy in aging. Memory retrieval decline in older women in comparison with young women while computerized training at home is shown. The elderly achieving results which are comparable to the youngs are determined by significantly increased duration while performing the memory tasks. To reveal factors of the CCTP's efficiency, age-related differences in the attention systems using the Attention Network Test were resolved. In the group of older women, VSWM efficiency is negatively related to the errors of incongruent information selection whereas in young women—to the reaction time while testing. Thus, the success of long-term systematic training of visuospatial memory in old age is strongly related to the high level of executive control.

Keywords: age, visuospatial short-term working memory, memory training, executive control

1. Introduction

The growing part of seniors in population into economically developed countries is associated with a risk of cognitive dysfunctions and brain ischemia due to cardiovascular disease (CVD) that has prompted numerous studies on the mechanisms of brain aging. Age-induced structural and functional changes in the brain including neuronal death, loss of synapses, and dysfunction of neuronal networks relate to such cognitive changes as a decline in the speed of mental activity, inhibitory processes, and short-term memory, including visuospatial short-term memory [1–6].

Aging is a complicated process that has a broad impact on human being in all countries. Aging has some unwelcome consequences to result such as the appearance of neurodegenerative processes and age-related atherosclerotic vascular disruptions which are cause cognitive deficits in elder age [7, 8].

However, there are several important modulating factors that do a preservation impact on cognitive functions in late ontogenesis, which are—education, occupational

IntechOpen

cognitive activity, locomotor activity, and eating habits. These factors and other conditions in the developmental context are build up compensatory brain resources that form through the lifespan of a person [9, 10]. Aging is a complicated process of the human being. It has some unwelcome consequences to result, such as the appearance of neurodegenerative processes and age-related atherosclerotic vascular disruptions which cause a cognitive deficit in elder age.

A meta-analysis of studies that goals investigation of the forces and trends of cognitive functions, related to various periods of the ontogenesis, shows—there is significant variability of these processes. Consequently, the conclusion of the meta-analysis point to the necessity of further studies aimed to clarify which factors stimulate or prevent cognitive deficits, and what is their weight [10]. The noted variability is due to the fact that almost every age effect is a multicomponent phenomenon, sensitive to the peculiarities of the tasks, the research context, and motivation when doing CCTPs.

Moreover, almost every cognitive task can be performed on the basis of different individual strategies. This means that they are differently associated with aging and include different neural mechanisms for its implementation. Thus, because of the multifactoriality of the research subject, it is difficult to generalize and compare the effects in the studied age groups.

The hypotheses about the role of the plasticity of functional neural networks and lifelong learning in the formation and maintenance of cognitive reserves are widely known. Armed with those ideas, researchers develop CCTP or/and brain training games (BTG). And there are numerous studies of their effect on the preservation of mental health and the prevention of dementia and other cognitive impairments [11–16]. Despite the positive effect described by different authors according to the indicators of motor response and functions of attention and memory [11, 15, 17, 18], accompanied by structural changes with an increase in the mass of gray and white matter of the brain and the reorganization of its functional activity [19, 20], the question remains about the long-term beneficial effect of CCTP. In addition, further researches are warranted to determine the expansion of cognitive-training-related effects to the general state of cognitive activity necessary for daily adaptation [20, 21]. Some researchers to increase the probability of this expansion propose to pay attention to the personalization of a CCTP, and to increase efficiency—to perform the training not individually, but in groups [11]. However, according to another point of view, exactly individualized computerized cognitive training may enhance cognitive self-efficacy in healthy seniors [22].

There are also results showing a positive effect of BTG on cognitive function only in a group of healthy subjects [23]. It should also be noted that some authors point out that different computerized brain training programs work in different ways. The plasticity-based cognitive training programs have a positive effect on cognitive ability, while the computer game training program, which also involves cognitive functions, does not [24].

A meta-analysis reported promising effects of both working memory training and executive functioning training on cognitive functioning in healthy adults aged 60 years and older [25]; albeit, the findings have been contested [26]. A recent analysis of publications on CCTP failed to provide evidence of a significant improvement in cognitive function after computerized cognitive training interventions lasting at least 12 weeks on cognitive function in cognitively healthy people [27]. The authors note that further research is required, possibly longer training, to achieve a sustainable CCTP outcome.

Indeed, 10-year cognitive training data for older people living in the commune show improvements in their cognitive functions not only as a result of subjective

assessment, but also in psychometric measurements of reasoning ability or reaction rate, but not memory [18]. It should be noted that there is a lack of scientific evidence for the effectiveness of cognitive training, and perceptions of its benefits are driven by the commercialization of this industry (see e.g., Harrell et al. [28]). Such conflicting points of view require clarification of the reasons for this discrepancy.

There are evidence for age-related atrophy in several brain regions, more often including the hippocampus and prefrontal cortex [29, 30]. The findings suggest that age-related decline in memory can be linked to encoding processes as well as to general cognitive-control operations.

One of the well-known theories to explain the cognitive deficit associated with aging is the theory of "frontal aging" [31, 32], according to which its main cause is the weakening of inhibitory functions during the selection of incongruent information and executive control of problem-solving choice and behavior in general. It was shown that older adults are able to improve inhibition performance through practice [33], and repetition learning is effective in enhancing VSWM in aging and acts through modifications at different stages of stimulus processing [34]. There is evidence for greater interference on a visuospatial compared with a verbal span task (see also Park et al. [35]). The task requires the participant to remember the presented particular blocks. It is believed to involve a number of components important to VSWM—encoding of visual stimuli, maintenance of that information, and memory retrieval. Some studies have already shown that encoding strategies are modified by aging, notably self-initiated strategies [36].

Considering the above-mentioned diversity in opinions regarding the effectiveness of cognitive training, the purpose of our study was to elucidate the age-related characteristics of the temporal dynamics of VSWM and to determine the value of executive control of behavior when testing VSWM.

2. Materials and methods

2.1 Design

Prospective, single-center, single-arm, nonrandomized study conducted at students/listeners of the Novosibirsk State Technical University (NSTU).

2.2 Participants

For investigation of differences in the time dynamics of the effectiveness of VSWM training in dependency of age, we recruited two groups of volunteers. The first group—the elderly—contained 65 women of retirement age (66.3 ± 8.5 years) who studied instruction of the Public Faculty of NSTU. This group had designated as GrE1. The second group—the youngs—contained 94 female students of NSTU's psychology chair (20.1 ± 1.7 years). This group had designated as GrY1.

At the second stage was performed the analysis of the relationship between VSWM and executive control of behavior in the ANT model. These 56 women formed a group designated as GrE2.

The reason for the female composition of the studied groups consisted in the overwhelming majority of the students-retirees (98%) of the Public Faculty are women. Therefore, for comparison VSWM, the group of young participants in the study was also formed only of girls. Moreover, as cerebrovascular accidents were more frequent in women [37], assessing the possibilities of activating their cognitive reserves through VSWM training seems to be practically useful.

2.3 Procedures

For the VSWM, the workout was used a computerized version of the modified "Visual Patterns test" [38]. The program shows a series of randomly generated spatial patterns of blue squares (**Figure 1A**). The presentation of spatial patterns produces in a 6 × 6 matrix. The minimum number of stimuli was 3, the maximum was 13. The pattern of stimuli was displayed for 2 seconds and then disappeared.

According to the instruction, after disappearing the blue-colored spatial pattern, a subject tries to reproduce this pattern by clicking on the unfilled matrix.

The correctly clicked cells turn green (**Figure 1B**), while the wrong clicked cells become red. In case when the reproducing of a pattern is out of time, the whole trial regards as incorrect (**Figure 1C**). In this case, a trial repeats with the pattern of the same number of the blue squares (re-located randomly). The total allowed number of incorrect trials in the one session is limited to 5.

If a trial of reproducing a pattern was successful (i.e., all cells turned green from the first try without any mishits) it regards as correct. In this case, a subject is moved to the next pattern with the increased number of blue squares by 1.

The experimental session overs in two conditions:

1. The number of blue squares in pattern reaches the pre-set maximum [13];

2. A subject reaches the limit of the allowed incorrect trials [5].

One whole session contains 11 trials with 88 blue squares in total.

Each participant was requested to complete 5 sessions of visuospatial memory testing.

The experimental procedure was supported by web-based software that we specially developed. It is available for authorized access at http://psytest.nstu.ru/tests/23/.

An example stimuli presentation to testing the visuospatial working memory (a screenshot from the software that was used in the training):

The efficiency of memory was determined in the percentage of the maximum possible stimuli retrieval—100% reflected the correct reproduction of 88 stimuli presented in 11 trials (using one session).

Instructions for training memory at home were given to students in practical classes in psychology. Students of the Public Faculty—received the instructions in a lecture on the psychophysiology of brain aging, followed by the practice of testing memory in a computer class. Participants were asked to further systematically

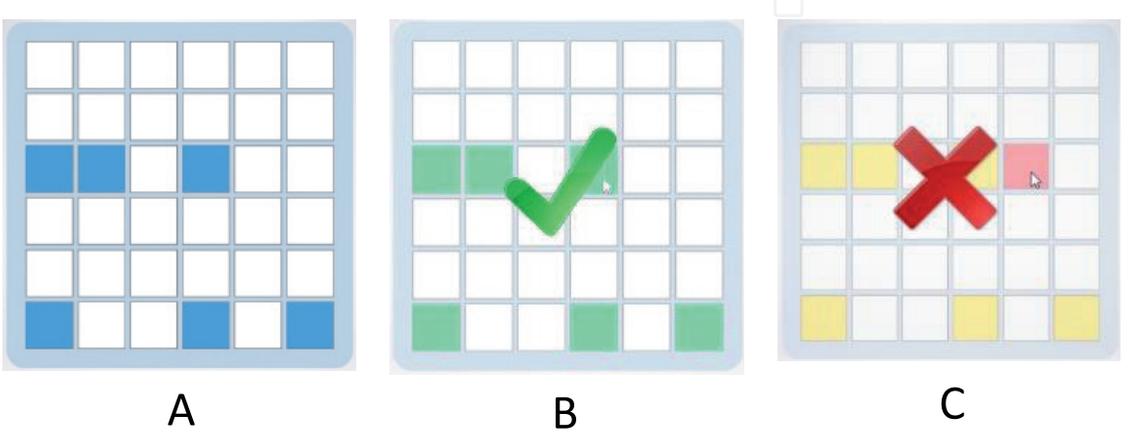


Figure 1.
Randomly generated spatial pattern—A; correctly clicked cells and correct trial—B; incorrect trial—C.

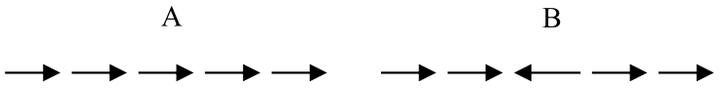


Figure 2.
Stimuli for determining the functions of the executive attention system: A—Congruent, B—Incongruent.

perform the task in order to achieve 80–100% efficiency of VSWM reproduction. The results of all sessions were saved to a database on the university server.

To estimate the function of the executive system of attention was used a computerized method, developed as part of the approach to assessing attention systems (Attention Network Test, ANT) [39] (programmer A.M.Suslov, A.S. 2012617379 dated 16.08.2012). The index of the functiotn of the executive attention system (RTex) was calculated as the difference in response time to the central arrow in the situation of selection of congruent (RTc) (**Figure 2A**) and incongruent (RTnc) (**Figure 2B**) stimuli. The number of errors in response to congruent and incongruent stimuli (Nc and Nnc, respectively) was also recorded.

The software package StatSoft Statistica 13.3.1 Ru AXA805I391121ARCN5-S was used for statistical data processing.

3. Results

3.1 Age differences in visuospatial short-term memory and time dynamic during training

A one-way ANOVA (AGE factor) was used to analyze the effectiveness of memory recall in the first testing session. A significant effect of the AGE factor was found: $F(1, 157) = 53.13$, $p = 0.00000$, $\eta 2 = 0.25$, due to lower values of reproduction in GrE1 compared to GrY1 (50.1 ± 2.0 and 68.7 ± 1.6, respectively). **Table 1** shows the distribution of VSWM efficiency in the first test depending on age, from which it follows that in GrE1 only 16.9% demonstrated retrieval better than 60%, while in GrY1 61.6%. The training criterion in GrY1 already at the first testing reached 28.7%, while in GrE1—only 1.5% (1 person).

The observed decrease in VSWM efficiency in GrE1 compared to GrY1 is consistent with data from other studies of age-related differences in visual-spatial memory [4, 40–43].

The trajectory of the intensity of memory training in two age groups is shown in **Figure 3**—after the first five sessions, the number of participants in training from GrE1 systematically increases compared to GrY1. Analysis of the dynamics of memory retrieval in the first five sessions showed significant effects of the AGE and SESSION factors ($F(1, 88) = 34.41$; $p < 0.00001$, $\eta 2 = 0.31$ and $F(3, 264) = 11.44$; $p < 0.00000$, $\eta 2 = 0.13$, respectively), due to lower memory indices in GrE1 compared to GrY1 (54.0 ± 2.2 and 71.1 ± 1.9) and a similar dynamics in the groups of increase in indices in the 4th and 5th sessions compared to the 1st

Group	Retrieval (%)							
	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
GrE1	3,1	15,4	40,0	24,6	12,3	3,1	0,0	1,5
GrY1	1,1	4,3	7,4	25,5	22,3	10,6	11,7	17,0

Table 1.
The effectiveness of VSWM retrieval in the groups of elderly (GrE1) and young (GrY1) women.

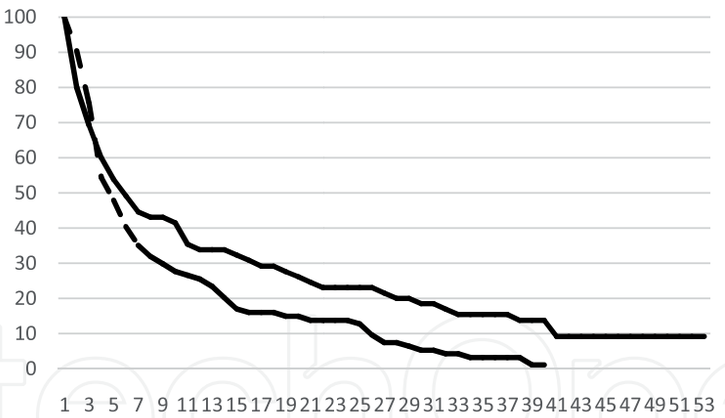


Figure 3.
Change in the number (%) of young (dotted line) and elderly (solid line) participants in memory training depending on the session number (x-axis).

(0.00000 < p < 0.000002 with post hoc analysis of the SESSION effect with Bonferroni correction).

Up to 30 training sessions in GrE1 were performed by 18.5% of the study participants, and in GrY1—only 5.3%. However, this small part of GrY1 achieved an improvement in VSWM retrieval, while GrE1 failed to achieve the criterion required according to the instructions (**Figure 4**).

The observed decrease in the number of participants in cognitive training in GrE1 is similar to that obtained in the course of the Finnish geriatric study aimed at preventing cognitive impairment [44]. Despite the positive effect of long-term training, only a small part of GrE1 achieved it. Therefore, we should agree with the conclusion that home workouts without external control of their implementation are not effective enough [45] for those people who do not have high self-control over their activities.

Five people from GrE1 continued their memory training for over 3 months. The effect of improving their memory in session 87 according to the Wilcoxon criterion was significantly higher than in the first one ($p = 0.04$) (**Figure 5**), and the average value of reproduction reached the proposed criterion of 80%.

Thus, the internal motivation for starting memory training is insufficient to achieve its effectiveness in GrE1, since most of its participants stop performing the task after only five trials, without achieving the required effect of improving memory. Persistence in VSWM training manifested by a small part of GrE1

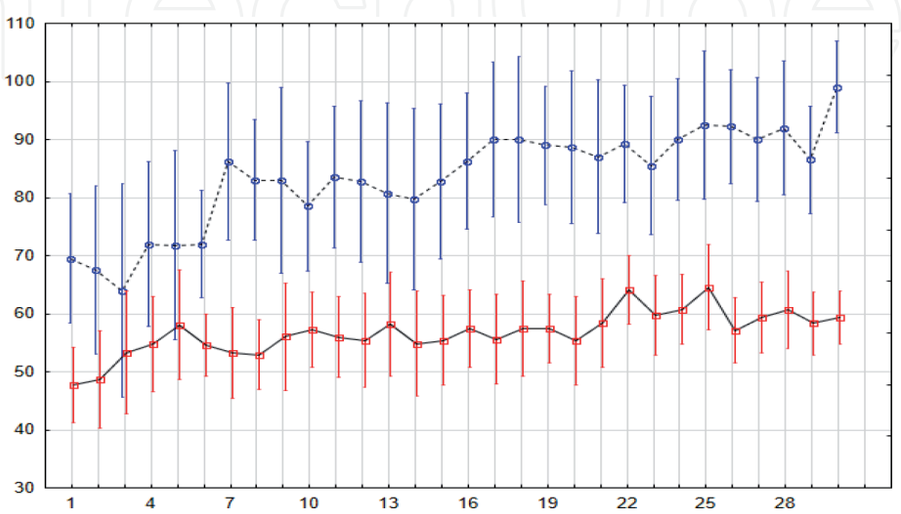


Figure 4.
The efficiency of memory reproduction in groups of young (dotted line) and elderly (solid line) participants in memory training, depending on the session number (x-axis).

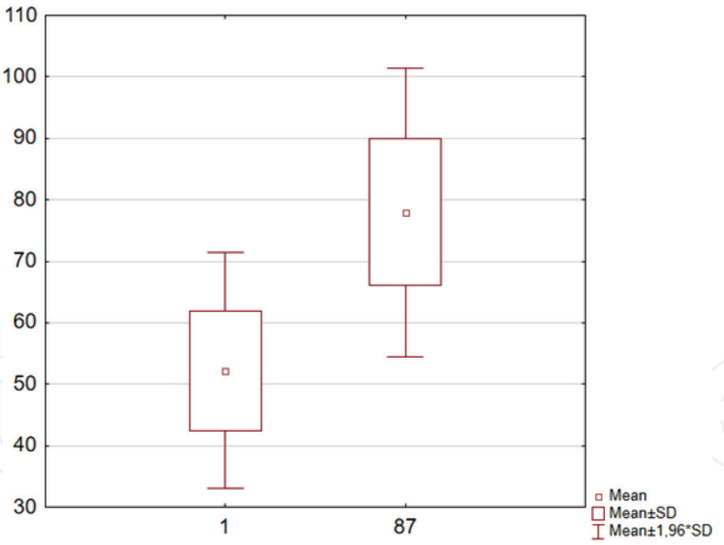


Figure 5.
Memory recall efficiency in the long-term training group during the first test and in the 87th session.

indicates the possibility of achieving a positive effect only when more than 80 sessions are implemented within 3 months, while in GrY1 seven sessions are enough to increase the effectiveness of VSWM.

The effectiveness of performing VSWM tasks is associated with the influence of practice and interference processes, each of which has an age specificity, and the combination of a higher learning rate with more pronounced interference in young people than in old age can determine the individual effectiveness of cognitive training [43, 46].

Several factors are also known to support long-term cognitive training. These include the possession of high behavior control, intrinsic motivation to achieve a goal, and interest in the performed activity, including due to the awareness of the development of cognitive deficits [22, 28, 47]. Previously, it was shown that when assessing motivational inducers of behavior, older women single out cognitive training as a priority in maintaining their health; however, only 8% of this group actually consistently participated in cognitive training using a battery of computerized techniques [48]. Consequently, the different age dynamics of memory training noted by us can be associated with the dominance of the learning potential in GrY1 and motivation to perform the task in GrE1.

It is believed that aging is associated with the effect of increased costs of cognitive interaction and increased effort required to achieve a high level of task performance [49, 50]. Therefore, older people become more selective and economical in the use of cognitive resources, which is reflected in a decrease in intrinsic motivation to participate in predictably complex cognitive activities. Apparently, therefore, the lack of visible success after the first training sessions causes them to refuse further activities. Individualized cognitive training with feedback that reinforces subjective assessments of change can help to improve cognitive self-esteem in older adults [22], and success can help to reduce perceptions of difficulties and become more willing to participate in cognitive activities [50].

It has been shown that the effectiveness of cognitive training can be increased due to involvement in activities and increased motivation through learning cognitive control using play procedures or nonplay learning [51]. Improving visual memory is possible through the application of a strategy for controlling attention and directing it to target memory components [40].

In this regard, the next stage of our study was devoted to elucidating the relationship between VSWM and executive attention control.

3.2 Role of executive control in the efficiency of the visuospatial short-term memory

This stage of the research was devoted to the analysis of the relationship between VSWM and executive control of behavior in the ANT model.

VSWM assessment was carried out according to the method described in clause 3.1 above.

The indicators of attention and memory in the studied groups are shown in **Table 2**. According to the intergroup comparison, all indicators differed significantly—GrE2 was characterized by lower memory values, but a large number of errors and a longer reaction time when testing executive control of attention.

By the correlation analysis of the ratio of VSWM and attention indices in each group a negative relationship was found between the VSWM efficiency with Nnc in GrE2 ($r = -0.31$, $p < 0.02$) and with RTnc ($r = -0.35$, $p < 0.01$) in GrY2.

Consequently, in GrE2, the memorization efficiency is associated with the control of the accuracy of information selection, and in GrY2, with the information selection rate.

The relationship between executive control and working memory, including VSWM, is well known [52–54], but continues to attract the interest of researchers since their age-related changes determine preservation of intellectual abilities and quality of life during aging [55]. According to the results of tomographic studies, cortical thinning of the right anterior cingulate and middle frontal gyri showed progression from mild cognitive impairment (MCI) to Alzheimer's disease (AD) [52]. Since these brain structures are associated with such WM functions as the selection of information relevant for memorization and inhibition of irrelevant information, tracking executive function performance can be a useful tool to assess an individual's cognitive abilities in older adults as well as a strong predictor of progression from MCI to AD. In this regard, executive attention control training is included in complex multimodal cognitive training programs for patients with MCI [56]. Our data are consistent with these views, indicating a positive relationship between the effectiveness of the executive functions of attention and VSWM. It is noteworthy that if in GrY2 a high speed of information selection is required for successful reproduction of VSWM, then in GrE2 the predominant role is played by the selection accuracy with inhibition of irrelevant stimuli. Consequently, regardless of the general slowdown in the rate of cognitive processes characteristic of old age [5, 6, 37, 57], such a reorganization of information selection is possible, in particular, through the strategy of redistribution of directed attention [40] or modifications at different stages of stimulus processing [34], which provides an effective VSWM.

Thus, according to the results of the second part of the study, the preservation of executive control of attention should be recognized as a necessary condition for successful long-term VSWM training in GrE1.

Group	VSWM	ANT				
		Nc	Nnc	RTc	RTnc	RTex
GrE2	67.9 ± 7.4***	0.3 ± 0.5*	3.5 ± 4.3***	841 ± 159***	952 ± 157***	111 ± 56**
GrY2	82.5 ± 7.6	0.1 ± 0.3	1.5 ± 2.3	541 ± 77	634 ± 90	93 ± 42

*<0.05.
**<0.01.
***<0.001.

Table 2.
Indicators of attention and memory in the elderly group (GrE2) and young group (GrY2).

4. Conclusion

The results obtained in our study show that despite the initially lower VSWM indicators in older women than in younger women, long-term (more than 3 months) training allows you to achieve a result comparable to that of young women; and because of that to achieve effectiveness in cognitive training in the elderly internal control of behavior is crucial.

Indeed, according to the results of the experiment to determine the ratio of VSWM and psychometric assessment of the functions of executive attention, the relationship between VSWM and exactitude processing of information selection in the elderly group is established.

Therefore, achieving an improvement in VSWM in old age requires persistence and a prolonged training period, which is provided by executive control of cognitive activity. The success of cognitive training at home for the individual execution of computerized programs is possible in the presence of internal motivation and high executive control of behavior.

Hence, memory decline as a consequence of cerebrovascular disease can be compensated by cognitive training and psychological support of insufficiently effective initially obtained results. Such support is natively possible in group of cognitive training programs at neurorehabilitation centers. Also, such a psychological support can be realized in computerized training programs in the form of feedback to emotional reinforcement. Especially when the current result are not satisfied and motivation for continue training are insufficient.

Acknowledgements

This study was supported by the Ministry of Science and Higher Education of Russian Federation (project No. FSUN-2020-0009). Conflict of Interest: The authors declare that they have no conflicts of interest.

Author details

Olga Razumnikova* and Vladislav Kagan
Novosibirsk State Technical University, Novosibirsk, Russia

*Address all correspondence to: razoum@mail.ru

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Harada CN, Natelson Love MC, Triebel KL. Normal Cognitive Aging. Clinics in Geriatric Medicine. 2013; **29**(4):737-752

[2] Hertzog C, Kramer AF, Wilson RS, Lindenberger U. Enrichment effects on adult cognitive development: Can the functional capacity of older adults be preserved and enhanced? Psychological Science in the Public Interest. 2008;**9**(1):1-65

[3] Hubert V, Beaunieux H, Chételat G, Platel H, Landeau B, Viader F, et al. Age-related changes in the cerebral substrates of cognitive procedural learning. Human Brain Mapping. 2009;**30**(4):1374-1386

[4] Perrochon A, Mandigout S, Petruzzellis S, Soria Garcia N, Zaoui M, Berthoz A, et al. The influence of age in women in visuo-spatial memory in reaching and navigation tasks with and without landmarks. Neuroscience Letters. 2018;**684**:13-17

[5] Razumnikova OM. Effects of aging brain and activation methods of its compensatory resources. Advances in Physiological Sciences. 2015;**46**(2):3-16 (In Russian)

[6] Salthouse T. Consequences of age-related cognitive declines. Annual Review of Psychology. 2012;**63**(1): 201-226

[7] Tarasova IV, Trubnikova OA, Razumnikova OM. Plasticity of brain functional systems as a compensator resource in normal and pathological aging associated with atherosclerosis. Ateroscleroz. 2020;**16**(1):59-67 (In Russian)

[8] Martinic-Popovic I, Simundic A-M, Dukic L, Lovrencic-Huzjan A, Popovic A, Seric V, et al. The association of inflammatory markers with cerebral vasoreactivity and carotid atherosclerosis in transient ischaemic attack. Clinical Biochemistry. 2014;**47**(16-17):182-186

[9] Chen P, Goedert KM, Murray E, Kelly K, Ahmeti S, Barrett AM. Spatial bias and right hemisphere function: Sex-specific changes with aging. Journal of the International Neuropsychological Society. 2011;**17**(3):455-462

[10] Rut C, Jose B, Antonieta N. Age-related cognitive changes: The importance of modulating factors. Journal of Geriatric Medicine Gerontology. 2018;**4**(2):48

[11] Kelly ME, Loughrey D, Lawlor BA, Robertson IH, Walsh C, Brennan S. The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta-analysis. Ageing Research Reviews. 2014;**15**:28-43

[12] Mahncke HW, Bronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: Scientific bases for a novel intervention. Progress in Brain Research. 2006;**157**:81-109

[13] Campos-Magdaleno M, Leiva D, Pereiro AX, Lojo-Seoane C, Mallo SC, Facal D, et al. Changes in visual memory in mild cognitive impairment: A longitudinal study with CANTAB. Psychological Medicine. 2020;**7**:1-11

[14] McCallum S, Boletsis C. A taxonomy of serious games for dementia. In: Schouten B, Fedtke S, Bekker T, Schijven M, Gekker A, editors. Games for Health. Wiesbaden: Springer Fachmedien Wiesbaden; 2013. pp. 219-232

[15] Edwards JD, Phillips CB, O'Connor ML, O'Brien JL, Hudak EM, Nicholson JS. Applying the health belief model to quantify and investigate expectations for computerized cognitive

training. Journal of Cognitive Enhancement. 2021;**5**(1):51-61

[16] Edwards JD, Fausto BA, Tetlow AM, Corona RT, Valdés EG. Systematic review and meta-analyses of useful field of view cognitive training. Neuroscience & Biobehavioral Reviews. 2018;**84**:72-91

[17] Giuli C, Papa R, Lattanzio F, Postacchini D. The effects of cognitive training for elderly: Results from my mind project. Rejuvenation Research. 2016;**19**(6):485-494

[18] Rebok GW, Ball K, Guey LT, Jones RN, Kim H-Y, King JW, et al. Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. Journal of the American Geriatrics Society. 2014;**62**(1):16-24

[19] Jockwitz C, Caspers S, Lux S, Eickhoff SB, Jütten K, Lenzen S, et al. Influence of age and cognitive performance on resting-state brain networks of older adults in a population-based cohort. Cortex. 2017;**89**:28-44

[20] Nguyen L, Murphy K, Andrews G. Immediate and long-term efficacy of executive functions cognitive training in older adults: A systematic review and meta-analysis. Psychological Bulletin. 2019;**145**(7):698-733

[21] JIV B, JMJ M, Ridderinkhof KR. Brain training in progress: A review of trainability in healthy seniors. Frontiers in Human Neuroscience. 2012;**6**:183

[22] Goghari VM, Krzyzanowski D, Yoon S, Dai Y, Toews D. Attitudes and beliefs toward computerized cognitive training in the general population. Frontiers in Psychology. 2020;**11**:503

[23] Al-Thaqib A, Al-Sultan F, Al-Zahrani A, Al-Kahtani F, Al-Regaiey K, Iqbal M, et al. Brain training games enhance cognitive function in healthy subjects. Medical Science Monitor Basic Research. 2018;**24**:63-69

[24] Mahncke HW, DeGutis J, Levin H, Newsome MR, Bell MD, Grills C, et al. A randomized clinical trial of plasticity-based cognitive training in mild traumatic brain injury. Brain. 2021;**144**(7):1994-2008

[25] Karbach J, Verhaeghen P. Making working memory work: A meta-analysis of executive-control and working memory training in older adults. Psychological Science. 2014;**25**(11): 2027-2037

[26] Melby-Lervåg M, Hulme C. Is working memory training effective? A meta-analytic review. Developmental Psychology. 2013;**49**(2):270-291

[27] Gates NJ, Rutjes AW, Di Nisio M, Karim S, Chong L-Y, March E, et al. Computerised cognitive training for 12 or more weeks for maintaining cognitive function in cognitively healthy people in late life. Cochrane Dementia and Cognitive Improvement Group, editor. Cochrane Database of Systematic Reviews. 2020;**2**(2):CD012277

[28] Harrell ER, Kmetz B, Boot WR. Is cognitive training worth it? exploring individuals' willingness to engage in cognitive training. Journal of Cognition Enhancement. 2019;**3**(4):405-415

[29] Fjell AM, Walhovd KB, Fennema-Notestine C, McEvoy LK, Hagler DJ, Holland D, et al. One-year brain atrophy evident in healthy aging. Journal of Neuroscience. 2009;**29**(48): 15223-15231

[30] Nyberg L, Salami A, Andersson M, Eriksson J, Kalpouzos G, Kauppi K, et al. Longitudinal evidence for diminished frontal cortex function in aging. Proceedings of the National Academy of Sciences. 2010;**107**(52):22682-22686

[31] Denburg NL, Hedgcock WM. Age-associated executive dysfunction, the prefrontal cortex, and complex decision making. Aging and Decision Making. 2015:79-101

[32] West RL. An application of prefrontal cortex function theory to cognitive aging. Psychological Bulletin. 1996;**120**(2):272-292

[33] Wilkinson AJ, Yang L. Inhibition plasticity in older adults: Practice and transfer effects using a multiple task approach. Neural Plasticity. 2016; **2016**:1-12

[34] Tagliabue CF, Assecondi S, Cristoforetti G, Mazza V. Learning by task repetition enhances object individuation and memorization in the elderly. Scientific Reports. 2020;**10**(1): 19957

[35] Park DC, Lautenschlager G, Hedden T, Davidson NS, Smith AD, Smith PK. Models of visuospatial and verbal memory across the adult life span. Psychology and Aging. 2002;**17**(2):299-320

[36] Craik FI. Changes in memory with normal aging: A functional view. Advances in Neurology. 1990;**51**:201-205

[37] Calatayud E, Salavera C, Gómez-Soria I. Cognitive Differences in the Older Adults Living in the General Community: Gender and Mental Occupational State Study. Int J Environ Res Public Health. 17 Mar 2021;**18**(6):3106. DOI: 10.3390/ ijerph18063106. PMID: 33802961; PMCID: PMC8002664.99

[38] Della Sala S, Gray C, Baddeley A, Allamano N, Wilson L. Pattern span: A tool for unwelding visuo–spatial memory. Neuropsychologia. 1999;**37**(10):1189-1199

[39] Fan J, McCandliss BD, Sommer T, Raz A, Posner MI. Testing the efficiency and independence of attentional networks. Journal of Cognitive Neuroscience. 2002;**14**(3):340-347

[40] Allen RJ, Atkinson AL, Nicholls LAB. Strategic prioritisation enhances young and older adults' visual feature binding in working memory. Quarterly Journal of Experimental Psychology. 2021;**74**(2):363-376

[41] Beigneux K, Plaie T, Isingrini M. Aging effect on visual and spatial components of working memory. International Journal of Aging & Human Development. 2007;**65**(4):301-314

[42] Rhodes S, Parra MA, Logie RH. Ageing and feature binding in visual working memory: The role of presentation time. Quarterly Journal of Experimental Psychology. 2016;**69**(4): 654-668

[43] Rowe G, Hasher L, Turcotte J. Age differences in visuospatial working memory. Psychology and Aging. 2008;**23**(1):79-84

[44] Turunen M, Hokkanen L, Bäckman L, Stigsdotter-Neely A, Hänninen T, Paajanen T, et al. Computer-based cognitive training for older adults: Determinants of adherence. Ginsberg SD, editor. PLoS One. 2019;**14**(7):e0219541

[45] Lampit A, Hallock H, Valenzuela M. Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. Gandy S, editor. PLoS Medicine. 2014;**11**(11):e1001756

[46] Razumnikova O. Age effect on relationships between inhibitory functions of executive attention system and visual memory. Experimental Psychology (Russia). 2019;**12**(2):61-74

[47] Mohammed S, Flores L, Deveau J, Cohen Hoffing R, Phung CM, Parlett C,

et al. The benefits and challenges of implementing motivational features to boost cognitive training outcome. Journal of Cognition of Enhancement. 2017;**1**(4):491-507

[48] Razumnikova OM, Asanova NV. Motivational inductors of behavior as reserves of successful aging. Advances in Gerontology. 2019;**9**(3):361-365

[49] Hess TM. Selective engagement of cognitive resources: Motivational influences on older adults' cognitive functioning. Perspectives on Psychological Science. 2014;**9**(4):388-407

[50] Hess TM, Lothary AF, O'Brien EL, Growney CM, DeLaRosa J. Predictors of engagement in young and older adults: The role of specific activity experience. Psychology and Aging. 2021;**36**(2):131-142

[51] Vervaeke J, Hoorelbeke K, Baeken C, Van Looy J, Koster EHW. Transfer and motivation after cognitive control training for remitted depression in healthy sample. Journal of Cognitive Enhancement. 2020;**4**(1):49-61

[52] Kirova A-M, Bays RB, Lagalwar S. Working memory and executive function decline across normal aging, mild cognitive impairment, and Alzheimer's disease. BioMed Research International. 2015;**2015**:1-9

[53] Miyake A, Friedman NP, Rettinger DA, Shah P, Hegarty M. How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. Journal of Experimental Psychology: General. 2001;**130**(4):621-640

[54] Wang L, Bolin J, Lu Z, Carr M. Visuospatial working memory mediates the relationship between executive functioning and spatial ability. Frontiers in Psychology. 2018;**9**:2302

[55] Borella E, Cantarella A, Joly E, Ghisletta P, Carbone E, Coraluppi D, et al. Performance-based everyday functional competence measures across the adult lifespan: The role of cognitive abilities. International Psychogeriatrics. 2017;**29**(12):2059-2069

[56] Tsolaki M, Kounti F, Agogiatou C, Poptsi E, Bakoglidou E, Zafeiropoulou M, et al. Effectiveness of nonpharmacological approaches in patients with mild cognitive impairment. Neurodegenerative Diseases. 2011;**8**(3):138-145

[57] Eckert. Age-related changes in processing speed: Unique contributions of cerebellar and prefrontal cortex. Frontiers in Human Neuroscience. 2010;**4**:10