Journal of Physical Education and Sport ® (JPES), Vol. 21 (5), Art 333, pp. 2473 - 2479, September 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effects of karate training on cognitive functions in young athletes

BLANKA DWOJACZNY[1], MONIKA BEJTKA[2], SERGII IERMAKOV[3], VLADIMIR POTOP[4], TETIANA YERMAKOVA[5], MIROSŁAWA CIEŚLICKA[6]
[1,2,6]Department of Human Physiology, Nicolaus Copernicus University, Collegium Medicum Bydgoszcz, POLAND
[3]Department of Sports, Gdansk University of Physical Education and Sport, POLAND
[4]Department of Physical Education and Sport, University of Pitesti, ROMANIA
[3,5]Department of Pedagogy, Kharkiv State Academy of Design and Arts, UKRAINE

Published online: September 30, 2021
(Accepted for publication September 15, 2021)
DOI:10.7752/jpes.2021.05333

Abstract
Background and Study Aim: Several lines of evidence indicate that regular physical activity has a positive impact on cognitive function. Relatively limited number of studies describe the effects of long-term physical activity among athletes in specific sports fields. The purpose of these studies was to determine the interrelation between the regular karate training and level of selected cognitive functions of young karate athletes. Material and methods: We examined the influence of karate training on cognitive performance of young volunteers (n=24 males; aged 16,79 ± 0,86). To evaluate the cognitive performance in our subjects we used Face/Name Association Test, Stroop Test and Trail Making Test. The results were compared with control group (n=24 males; 16,08 ± 0,39). Participants of this study were young and healthy and therefore we can exclude impact of coexisting illness's cognitive function. Results: The mean results in the Face/Name Association Test in control group was 74,12 ± 6,66 % in the karate group 61,08 ± 5,36 % (p<0,005). Statistically different results were not observed in duration of the retrieval phase of this test (p<0,05). In the Stroop Test the mean result in control group was 269, 84 ± 84,18 seconds, in the karate group 289,50 ± 79,90 seconds (p<0,005). We observed statistical difference in results of Trial Making Test, in part A mean results in control group were 67,37 ± 13,20 seconds and karate group 85,63 ±21,46 seconds (p<0,005). In part B mean results were 80,37 ± 18,34 seconds and 89,41 ± 20,06 seconds in control and karate group, respectively (p<0,05). Conclusions: We demonstrated that karate training can lead to reduction of some cognitive function.
Key words: karate athletes, cognitive function, Stroop Test, Face/Name association, Trial Making Test

Introduction

It is well known that physical activity may have a positive impact on human cognitive functions (Złomańczuk et al., 2006; Erickson et al., 2009; Nakagawa et al., 2020; Niedermeier et al., 2020; Okudan, 2021). Several lines of evidence confirm that regular physical activity contributes to a number of adaptive changes in the body, that may affect the central nervous system. For example, it was shown that the systematic physical activity has influence on increasing angiogenesis and neurogenesis processes, increased blood flow through the brain and increase in grey matter volume in the temporal and frontal cortex (Leal-Galicia et al.,2019; Dawe et al., 2021; Maugeri et al., 2021; Mohammadi et al., 2021). A potential mechanism of the influence of physical activity on the cognitive function is related to the activation of neurotrophies, primarily brain derived neurotrophic factor (BDNF) and insulin-like growth factor 1 (IGF-1) which has a positive effect on the brain (Lindholm et al., 1996; Cameron et al., 1998; Spartano et al., 2019). BDNF is considered to be the main compound influencing the plasticity of the brain, the processes of synaptic functions development and axons. Activation of BDNF expression on synapses, as a result of increased motor activity, improves synaptic transduction, stimulation of genetic transcription, favourable reconstruction of the synapse and improvement of the elasticity of the neurons (Ip et al., 1993; Cotman, 2002; Zlibinaite et al., 2021). IGF-1 is involved in differentiation and growth of neurons. During physical activity, the concentration of IGF-1 increases in the brain and in peripheral blood, which results from the possibility of crossing the blood-brain barrier by this factor. Peripheral IGF-1 is responsible for the activation of growth factors cascade in the brain, stimulating mechanisms that increase its plasticity (Aleman et al., 1999; Arwert et al., 2005; Spartano et al., 2019). Furthermore, regular physical exercise contributes to the curtailment of inflammation by reducing the concentration of proinflammatory cytokines in the blood, which may contribute to the activation of neurodegenerative processes. This effect depends on the type of exercise, duration and its intensity (Gleeson et al., 2011; Liang et al., 2021). Finally, physical activity is also responsible for reducing the risk factors of the metabolic syndrome, primarily hypertension and insulin resistance thus, it lowers the risk of developing cognitive dysfunctions, optimizes the

Corresponding Author: VLADIMIR POTOP, E-mail: vladimir_potop@yahoo.com

functioning of the brain and delays and slows down the development of neurodegenerative disorders (Gleeson et al., 2011; Phillips et al., 2014; Coll-Padros et al., 2019).

The results of many studies have confirmed that the influence of exercise on the central nervous system depends on the type of physical activity (dynamic effort, effort with a predominance of a static component, resistance training). Different types of physical activity, through different action mechanisms, affect various neural pathways (Cassilhas et al., 2007; Yukhymenko et L., 2019; Mihailescu et al., 2021). It seems particularly important to define which type of physical activity has the most beneficial effect on cognitive functions. So far, majority of research focus on the positive effect of regular, moderate physical activity on cognitive performance (Ploughman, 2008; Hötting & Röder, 2013; Ceylan & Günay, et al., 2020; Dwojaczny et al., 2020). Relatively limited number of studies describe the effects of long-term physical activity in athletes in specific sports disciplines (Pacesova et al., 2018; Dworska, 2020). The purpose of these studies was to determine the interrelation between the regular karate training and level of selected cognitive functions of young karate athletes.

Material and Methods

Participants. 48 volunteers took part in the research. The volunteers were divided into two groups: control and karate group. The control group consisted of local high school students (24 male; aged 16,08 ± 0,39). Based on surveys, the selected males who lead sedentary lifestyle and did not participate in any sporting activities except physical education lessons. Volunteers from the karate group were recruited from the local karate team (24 male; aged 16,79 ± 0,86). Athletes training from 5 to 7 years were qualified for the research. All volunteers were healthy and did not suffer from any chronic conditions. The study was conducted in accordance with the Declaration of Helsinki for Human Studies. The study protocol was approved by a local Ethics Committee.

Procedure. Evaluation of cognitive skills was based on scores from face/name association test. The detailed experimental protocols for these tests were described previously (Złomańczuk et al., 2006). Shortly, in the acquisition phase of the face/name association test, subjects were exposed to 100 faces – each associated with a single name on a computer screen. Each face/name pair was presented for 2 seconds. After 10 minutes from the end of acquisition phase the retrieval phase began. During this phase test subjects were presented with the same faces as in acquisition phase but each face was associated with two names, one of which was the same name as in acquisition phase. The task of the subject was to indicate the name associated with the face during acquisition phase. No time limits for retrieval phase were imposed. The percent of correctly associated names, and the duration of the retrieval phase were recorded for each subject.

The Stroop test consisted of four pages. The first test page contained the names of colours written in two columns in black ink (20 words in each column). The task was to read the names of colours. The second page contained the rows of cross marks in two columns (20 rows in each column). The rows of cross marks were displayed in different colours. A colour of each row was recognized and pronounced by each participant. The third and four pages contained the names of colours written in two 20-word columns. An ink colour was different than the name of a colour. The written name of a colour (third page) or the colour of the ink (four page) were recognized and pronounced by each subject. For each page the time of reading duration was recorded. In the statistical analysis we used the reading time of the last page expressed as a percentage of the first page reading time.

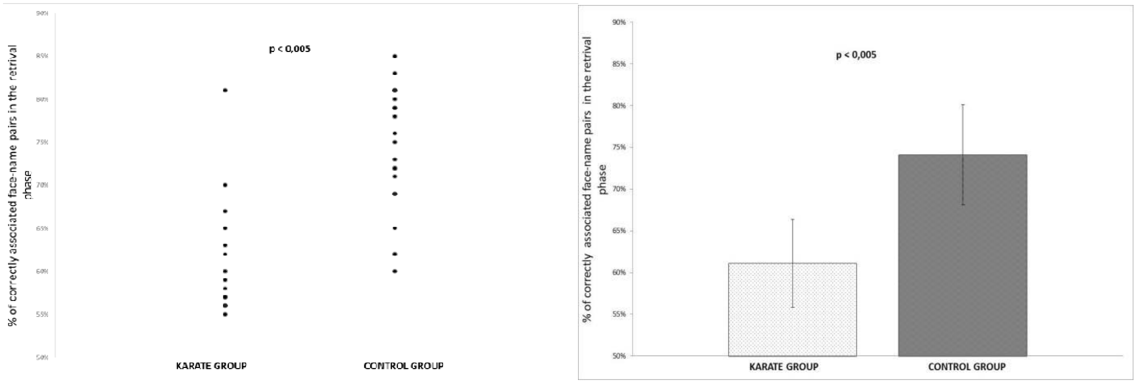
The Trail Making Test consisted of two pages. The first page contained numbers from 1 to 25 which are randomly arranged on a piece of paper. The task of the subject was to connect numbers of a continuous line (without revealing a papier pencil). The second page contained numbers (from 1 to 13) and letter (from A to L) which were randomly arranged on a paper. The task of the subject was to connect alternately numbers and letters (without revealing a paper pencil). The result of the test was the time it took to complete part A and part B, respectively.

All tests were performed between 9:00 am and 14 pm.

Statistical analysis. Statistical significance of the differences between the two groups was assessed using two-tailed T-Test. The results are presented as means with standard deviation. $p<0.05$ was considered statistically significant.

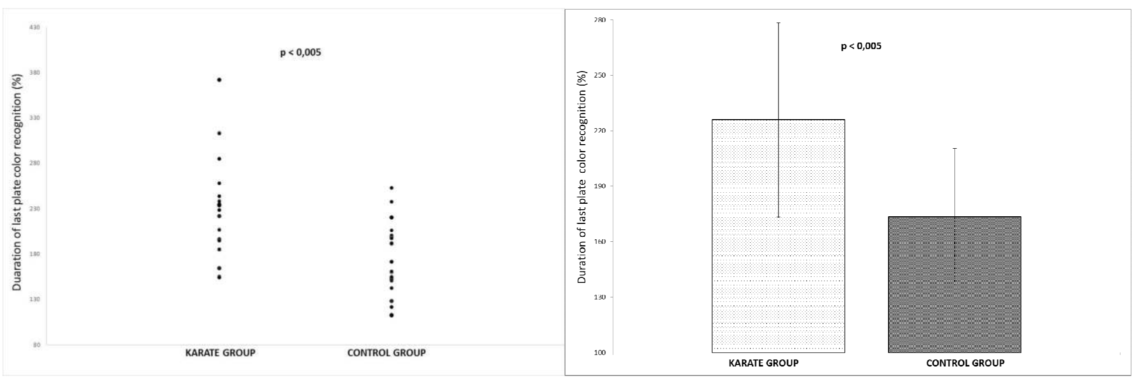
Results

In the control group, the average score of face/name association test was 74,12 ± 6,66 %. In the karate group the average score was 61,08 ± 5,36 % (Fig. 1a). The difference in the scores between control and the karate group was statistically significant, with $p<0.005$. No statistically significant difference ($p<0.5$) was observed between the two groups in the duration of the retrieval phase of the test. In the control group, mean retrieval duration equalled 269, 84 ± 84,18 seconds and in the karate group the retrieval duration was 289,50 ± 79,90 seconds (Fig. 1b). Statistically significant differences ($p<0,005$) were observed also between the two groups in the Stroop test. In the Stroop test, the control group reached the mean score of 173,44 ± 36,90 % and the score of karate group equalled 225,87 ± 52,56 % (Fig. 2). Statistically significant differences were observed between results control and karate group for part A Trial Making Test (p< 0,005). The mean results in TMT A in a control group was 67,37 ± 13,20 seconds, in karate group the mean result was 85,63 ±21,46 seconds (Fig.3a). Statistically differences were not observed in the part B Trial Making Test (p<0,5). The mean results in TMT B in the control group was 80,37 ± 18,34 seconds. In the karate group the mean result was 89,41 ± 20,06 seconds (Fig. 3b).



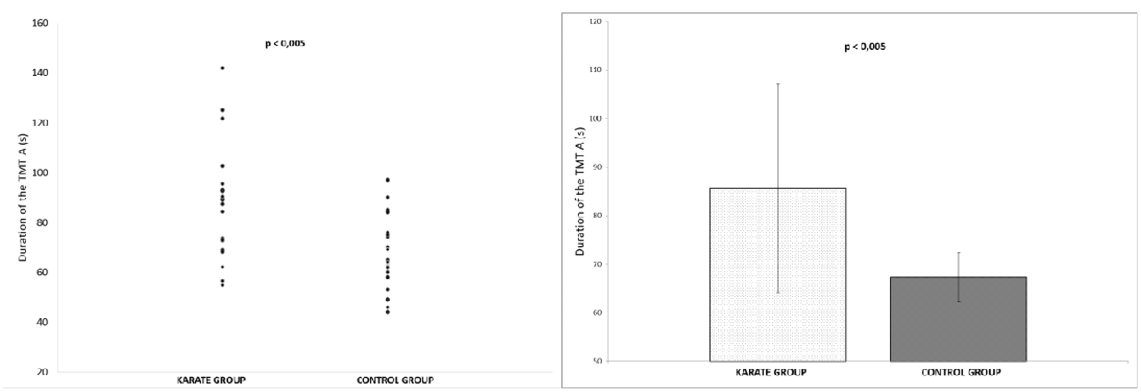
a) b)

Fig.1. Face/name association test results in karate and control groups. % of correctly associated name-face pairs in the retrieval phase: a) individual data points for all participants from the two groups; b) mean values for each group.



a) b)

Fig. 2 Stroop test results in karate and control groups. Duration of colour recognition for the last plate, expressed as % of the colour recognition duration for the first plate: a) individual data points for all participants from the two groups; b) mean values for each group.



a) b)

Fig. 3 Trial making test results in karate and control groups. Duration of the TMT A :a) individual data points for all participants from the two groups; b) mean values for each group.

Discussion

There are many reports indicating that regular physical activity is an important factor causing improvement of the level of cognitive skills (Kronenberg et al., 2003; Pomeshchikova et al., 2016; Ivashchenko et al., 2017; Kriventsova et al., 2017; Xiang Qian et al., 2020; Shenoy et al., 2021). However, the data presented in this report indicate that karate training can contribute to lowering the level of cognitive function. Volunteers from the karate group obtained worse score for accuracy measured by Face/name association test, Stroop test and Trial making test compared to the control group. The Face/name association test evaluates short term declarative memory which is closely associated with hippocampal activity (Sperling et al., 2001). The Stroop test measures multiple cognitive processes such as executive control, selective attention and ability to inhibit habitual responses. These abilities are strongly associated with the activity of prefrontal and anterior cingulate cortical areas (Barch, 2001; Li et al., 2021), while TMT test measures prefrontal cortex-dependent attention and cognitive flexibility (Tombaugh, 2004; Salas-Gomez et al., 2020). Our previous studies showed positive effect of physical activity on cognitive performance dependent on the hippocampus in particular (Złomańczuk et al., 2006; Dwojaczny et al., 2015).

Our findings are not concordant with the results from other studies which demonstrated that karate training can have a positive effect on some cognitive function. For example, it was shown that karate training contributes to the improvement of memory abilities and executive functioning particularly working memory, attention and executive functioning, among children with average age of 9 years (Alesi et al., 2019). In other studies, it was shown that 3-months karate training was related with an improvement of the cognitive functions (visual memory ability and executive function) in older adults (Lopes Filho, 2019) and athletes (Berti et al., 2019; Duru et al., 2020). On the other hand, Jansen and Dahmen-Zimmer showed that a few months karate training has no effect on cognitive functioning on elderly people (Jansen & Dahmen-Zimmer, 2012). Moreover, several studies report cognitive benefits derived from the practice of martial arts such as: Tai chi on attention task, working memory, delayed recall and subjective cognitive complaints (Man et al., 2010; Nguyen & Kruse, 2012; Yue et al., 2020).

In our research we observed that volunteers practicing karate have a lower level of cognitive functions compared to their peers who do not practice karate. It is very difficult to explain the mechanism that causes the reduction of cognitive functions in karate groups. Karate is a sport discipline which requires a lot of cognitive involvement. Karate athletes must entail in relevant tasks, inhibit irrelevant responses, update information, shift the focus of activities in action (Alesi et al., 2019; Duru et al., 2020). Participants of this study were young and healthy and therefore we can exclude impact of coexisting illness's cognitive function. However, one cannot exclude that the factors not controlled for in this study contributed to the final result, for example: different lifestyle, regularity of sleep hours, diet, sexual activity etc. These factors are also known to influence cognitive efficiency.

Conclusion

Our data demonstrate that karate training can have negative effect on cognitive function in young individuals. However, more research is needed to confirm our observations and elucidate the underlying mechanism of the influence of karate training on the level of cognitive functions. In order to confirm the negative influence of karate training on the level of cognitive functions, it seems necessary to determine the level of cognitive functions before starting karate training and after several years of training.

References:

Aleman, A., Verhaar, H. J. J., de Haan, E. H. F., de Vries, W. R., Samson, M. M., Drent, M. L., van der Veen, E. A., & Koppeschaar, H. P. F. (1999). Insulin-Like Growth Factor-I and Cognitive Function in Healthy Older Men. *The Journal of Clinical Endocrinology & Metabolism*, *84*(2), 471–475. https://doi.org/10.1210/jcem.84.2.5455

Alesi, M., Bianco, A., Padulo, J., Vella, F. P., Petrucci, M., Paoli, A., Palma, A., & Pepi, A. (2019). Motor and cognitive development: The role of karate. *Muscle Ligaments and Tendons Journal*, *04*(02), 114. https://doi.org/10.32098/mltj.02.2014.04

Arwert, L. I., Deijen, J. B., & Drent, M. L. (2005). The relation between insulin-like growth factor I levels and cognition in healthy elderly: A meta-analysis. *Growth Hormone & IGF Research*, *15*(6), 416–422. https://doi.org/10.1016/j.ghir.2005.09.001

Barch, D. M. (2001). Anterior Cingulate Cortex and Response Conflict: Effects of Response Modality and Processing Domain. *Cerebral Cortex*, *11*(9), 837–848. https://doi.org/10.1093/cercor/11.9.837

Berti, B., Momi, D., Sprugnoli, G., Neri, F., Bonifazi, M., Rossi, A., . . . Rossi, S. (2019). Peculiarities of Functional Connectivity-including Cross-Modal Patterns-in Professional Karate Athletes: Correlations with Cognitive and Motor Performances. *Neural Plasticity, 2019*. https://doi.org/10.1155/2019/6807978

Burdette, J.H., Laurienti, P.J., Espeland, M.A., Morgan, A., Telesford, Q., Vechlekar, C.D., Hayasaka, S., Jennings, J.M., Katula, J.A., Kraft, R.A., & Rejeski, W.J. (2010). Using Network Science to Evaluate Exercise-Associated Brain Changes in Older Adults. *Front Aging Neurosci*, *2*, 23.

Cameron, H.A., Hazel, T.G., & McKay, R.D. (1998). Regulation of neurogenesis by growth factors and neurotransmitters. *J Neurobiol.*, *36*, 287–306.

Cassilhas, R. C., Viana, V. A. R., Grassmann, V., Santos, R. T., Santos, R. F., Tufik, S., & Mello, M. T. (2007). The Impact of Resistance Exercise on the Cognitive Function of the Elderly. *Medicine & Science in Sports & Exercise*, *39*(8), 1401–1407. https://doi.org/10.1249/mss.0b013e318060111f

Ceylan, H., & Günay, A. (2020). Positional differences in anticipation timing, reaction time and dynamic balance of American football players. *Pedagogy of Physical Culture and Sports*, *24*(5), 227-239. https://doi.org/10.15561/26649837.2020.0503

Coll-Padros, N., Leon, M., Valech, N., Ros, E., Vidal, J., Estruch, R., . . . Rami, L. (2019). Physical activity is associated with better global cognition and frontal function in overweight/obese older adults with metabolic syndrome. *European Review of Aging and Physical Activity, 16*(1). https://doi.org/10.1186/s11556-019-0229-y

Cotman, C. (2002). Exercise: A behavioral intervention to enhance brain health and plasticity. *Trends in Neurosciences*, *25*(6), 295–301. https://doi.org/10.1016/S0166-2236(02)02143-4

Dawe, R. J., Yu, L., Leurgans, S. E., James, B. D., Poole, V. N., Arfanakis, K., . . . Buchman, A. S. (2021). Physical activity, brain tissue microstructure, and cognition in older adults. *Plos One, 16*(7). https://doi.org/10.1371/journal.pone.0253484

Duru, A. D., Balcioglu, T. H., Cakir, C. E. O., & Duru, D. G. (2020). Acute Changes in Electrophysiological Brain Dynamics in Elite Karate Players. *Iranian Journal of Science and Technology-Transactions of Electrical Engineering, 44*(1), 565-579. https://doi.org/10.1007/s40998-019-00252-0

Dwojaczny, B., Cieślicka, M., Tafil-Klawe, M., & Złomańczuk, P. (2015). The cognitive difference between student groups with high and low level of physical activity. *Medical and Biological Sciences*, *29*, 43–48.

Dwojaczny, B., Iermakov, S., Yermakova, T., & Cieślicka, M. (2020). The effect of acute exercise on cognition. *Physical Education of Students*, *24*(6), 325-331. https://doi.org/10.15561/20755279.2020.0604

Dworska, K. (2020). Wybrane funkcje wykonawcze u adolescentów uprawiających pływanie wyczynowe [Selected executive functions in adolescents practicing professional swimming]. *Annales Universitatis Mariae Curie-Skłodowska, Sectio J – Paedagogia-Psychologia*, *33*(2), 71. (In Polish). https://doi.org/10.17951/j.2020.33.2.71-84.

Erickson, K. I., Prakash, R. S., Voss, M. W., Chaddock, L., Hu, L., Morris, K. S., White, S. M., Wójcicki, T. R., McAuley, E., & Kramer, A. F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus*, *19*(10), 1030–1039. https://doi.org/10.1002/hipo.20547

Gleeson, M., Bishop, N. C., Stensel, D. J., Lindley, M. R., Mastana, S. S., & Nimmo, M. A. (2011). The anti-inflammatory effects of exercise: Mechanisms and implications for the prevention and treatment of disease. *Nature Reviews Immunology*, *11*(9), 607–615. https://doi.org/10.1038/nri3041

Hötting, K., & Röder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. *Neuroscience & Biobehavioral Reviews*, *37*(9), 2243–2257. https://doi.org/10.1016/j.neubiorev.2013.04.005

Ip, N., Li, Y., Yancopoulos, G., & Lindsay, R. (1993). Cultured hippocampal neurons show responses to BDNF, NT-3, and NT-4, but not NGF. *The Journal of Neuroscience*, *13*(8), 3394–3405. https://doi.org/10.1523/JNEUROSCI.13-08-03394.1993

Ivashchenko, O., Khudolii, O., Iermakov, S., Lochbaum, M., Cieślicka, M., Zukow, W., . . . Yermakova, T. (2017). Methodological approaches to pedagogical control of the functional and motor fitness of the girls from 7-9 grades. *Journal of Physical Education and Sport, 17*(1), 254-261. https://doi.org/10.7752/jpes.2017.01038

Jansen, P., & Dahmen-Zimmer, K. (2012). Effects of Cognitive, Motor, and Karate Training on Cognitive Functioning and Emotional Well-Being of Elderly People. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00040

Kriventsova, I., Pashkevych, S., Iermakov, S., Bartík, P., Michal, J., Nosko, M., & Yermakova, T. (2017). Fitness - aerobic training of 15-17 years age girl students, who have significant risk of deviations in backbone functional state. *Journal of Human Sport and Exercis*e, *12*(4), 1289-1297. https://doi.org/10.14198/jhse.2017.124.15

Kronenberg, G., Reuter, K., Steiner, B., Brandt, M. D., Jessberger, S., Yamaguchi, M., & Kempermann, G. (2003). Subpopulations of proliferating cells of the adult hippocampus respond differently to physiologic neurogenic stimuli. *The Journal of Comparative Neurology*, *467*(4), 455–463. https://doi.org/10.1002/cne.10945

Leal-Galicia, P., Romo-Parra, H., Rodriguez-Serrano, L. M., & Buenrostro-Jauregui, M. (2019). Regulation of adult hippocampal neurogenesis exerted by sexual, cognitive and physical activity: An update. *Journal of Chemical Neuroanatomy, 101*. https://doi.org/10.1016/j.jchemneu.2019.101667

Li, L., Yu, Q., Zhao, W. R., Herold, F., Cheval, B., Kong, Z. W., . . . Zou, L. Y. (2021). Physical Activity and Inhibitory Control: The Mediating Role of Sleep Quality and Sleep Efficiency. *Brain Sciences, 11*(5). https://doi.org/10.3390/brainsci11050664

Liang, J., Wang, H. Q., Zeng, Y., Qu, Y., Liu, Q., Zhao, F. Y., . . . Mu, D. Z. (2021). Physical exercise promotes brain remodeling by regulating epigenetics, neuroplasticity and neurotrophins. *Reviews in the Neurosciences, 32*(6), 615-629. https://doi.org/10.1515/revneuro-2020-0099

Lindholm, D., Carroll, P., Tzimagiorgis, G., & Thoenen, H. (1996). Autocrine-paracrine Regulation of Hippocampal Neuron Survival by IGF-1 and the Neurotrophins BDNF, NT-3 and NT-4. *European Journal of Neuroscience*, *8*(7), 1452–1460. https://doi.org/10.1111/j.1460-9568.1996.tb01607.x

Lopes Filho, B. J. P., Oliveira, C. R. de, & Gottlieb, M. G. V. (2019). Effects of karate-dô training in older adults cognition: Randomized controlled trial. *Journal of Physical Education*, *30*(1), 3030. https://doi.org/10.4025/jphyseduc.v30i1.3030

Man, D.W.K., Tsang, W.W.N., & Hui-Chan, C.W.Y. (2010). Do Older *T'ai Chi* Practitioners Have Better Attention and Memory Function? *The Journal of Alternative and Complementary Medicine*, *16*(12), 1259–1264. https://doi.org/10.1089/acm.2009.0462

Maugeri, G., D'Agata, V., Magri, B., Roggio, F., Castorina, A., Ravalli, S., . . . Musumeci, G. (2021). Neuroprotective Effects of Physical Activity via the Adaptation of Astrocytes. *Cells, 10*(6). https://doi.org/10.3390/cells10061542

Mihailescu, L., Dubiţ, N., Mihailescu, L. E., & Potop, V. (2021). Particularities of the changes in young swimmers' body adaptation to the stimuli of physical and mental stress in sports training process. *PeerJ*, *9*, e11659. https://doi.org/doi:10.7717/peerj.11659

Mohammadi, H., Gagnon, C., Vincent, T., Kassab, A., Fraser, S., Nigam, A., . . . Bherer, L. (2021). Longitudinal Impact of Physical Activity on Brain Pulsatility Index and Cognition in Older Adults with Cardiovascular Risk Factors: A NIRS Study. *Brain Sciences, 11*(6). https://doi.org/10.3390/brainsci11060730

Nakagawa, T., Koan, I., Chen, C., Matsubara, T., Hagiwara, K., Lei, H. J., . . . Nakagawa, S. (2020). Regular Moderate- to Vigorous-Intensity Physical Activity Rather Than Walking Is Associated with Enhanced Cognitive Functions and Mental Health in Young Adults. *International Journal of Environmental Research and Public Health, 17*(2), 14. https://doi.org/10.3390/ijerph17020614

Nguyen, M. H., & Kruse, A. (2012). A randomized controlled trial of Tai chi for balance, sleep quality and cognitive performance in elderly Vietnamese. *Clinical Interventions in Aging*, 185. https://doi.org/10.2147/CIA.S32600

Niedermeier, M., Weiss, E. M., Steidl-Muller, L., Burtscher, M., & Kopp, M. (2020). Acute Effects of a Short Bout of Physical Activity on Cognitive Function in Sport Students. *International Journal of Environmental Research and Public Health, 17*(10), 13. https://doi.org/10.3390/ijerph17103678

Okudan, B. (2021). Investigation of the relationship between cognitive behavioral physical activity and multiple intelligence levels in different team sports athletes. *Progress in Nutrition, 23*. https://doi.org/10.23751/pn.v23iS1.11610

Pacesova, P., Smela, P., Kracek, S., Kukurova, K., & Plevkova, L. (2018). Cognitive function of young male tennis players and non-athletes. *Acta Gymnica*, *48*(2), 56–61. https://doi.org/10.5507/ag.2018.011

Phillips, C., Baktir, M. A., Srivatsan, M., & Salehi, A. (2014). Neuroprotective effects of physical activity on the brain: A closer look at trophic factor signaling. *Frontiers in Cellular Neuroscience*, *8*. https://doi.org/10.3389/fncel.2014.00170

Ploughman, M. (2008). Exercise is brain food: The effects of physical activity on cognitive function. *Developmental Neurorehabilitation*, *11*(3), 236–240. https://doi.org/10.1080/17518420801997007

Pomeshchikova, I., Iermakov, S., Bartik, P., Shevchenko, O., Nosko, M., Yermakova, T., & Nosko, Y. (2016). Influence of exercises and games with ball on vestibular stability of students with muscular-skeletal apparatus disorders. *Sport Science, 9*(1), 75-83.

Salas-Gomez, D., Fernandez-Gorgojo, M., Pozueta, A., Diaz-Ceballos, I., Lamarain, M., Perez, C., . . . Sanchez-Juan, P. (2020). Physical Activity Is Associated With Better Executive Function in University Students. *Frontiers in Human Neuroscience, 14*. https://doi.org/10.3389/fnhum.2020.00011

Shenoy, S., Khandekar, P., & Sathe, A. (2021). High Intensity Intermittent Exercise Plays a Role in Improving Brain Activation During Complex Executive Functional Tasks. *Teorìâ Ta Metodika Fìzičnogo Vihovannâ*, *21*(1), 36-42. https://doi.org/10.17309/tmfv.2021.1.05

Spartano, N. L., Davis-Plourde, K. L., Himali, J. J., Murabito, J. M., Vasan, R. S., Beiser, A. S., & Seshadri, S. (2019). Self-Reported Physical Activity and Relations to Growth and Neurotrophic Factors in Diabetes Mellitus: The Framingham Offspring Study. *Journal of Diabetes Research, 2019*. https://doi.org/10.1155/2019/2718465

Sperling, R. A., Bates, J. F., Cocchiarella, A. J., Schacter, D. L., Rosen, B. R., & Albert, M. S. (2001). Encoding novel face-name associations: A functional MRI study. *Human Brain Mapping*, *14*(3), 129–139. https://doi.org/10.1002/hbm.1047

Tombaugh, T. (2004). Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology*, *19*(2), 203–214. https://doi.org/10.1016/S0887-6177(03)00039-8

Xiang Qian, X., Korobeynikov, G., Mishchuk, D., & Korobeynikova, L. (2020). Features of individual cognitive style of qualified badminton players. *Health, Sport, Rehabilitation*, *6*(4), 39-46. https://doi.org/10.34142/HSR.2020.06.04.04

Yue, C. L., Zou, L. Y., Mei, J., Moore, D., Herold, F., Muller, P., . . . Zhang, Z. H. (2020). Tai Chi Training Evokes Significant Changes in Brain White Matter Network in Older Women. *Healthcare, 8*(1). https://doi.org/10.3390/healthcare8010057

Yukhymenko, L., Makarchuk, M., Natalia, I., Korobeynikova, L., Korobeynikov, G., Borysova, O., . . . Gorashchenco, A. (2019). Links between system of information processing in brain and heart rate among athletes with different individual-typological characteristic. *Journal of Physical Education and Sport, 19*, 1041-1047. https://doi.org/10.7752/jpes.2019.s3150

Zlibinaite, L., Skurvydas, A., Kilikeviciene, S., & Solianik, R. (2021). Two Months of Using Global Recommendations for Physical Activity Had No Impact on Cognitive or Motor Functions in Overweight and Obese Middle-Aged Women. *Journal of Physical Activity & Health, 18*(1), 52-60. https://doi.org/10.1123/jpah.2020-0055

Złomańczuk, P., Milczarek, B., Dmitruk, K., Sikorski, W., Adamczyk, W., Zegarski, T., Tafil –Klawe, M., Chęsy, G., Klawe, J.J., & Rakowski, A. (2006). Improvement in the face-name association performance after three months of physical training in elderly women. *Journal of Physiology and Pharmacology, 57,* 417–424.