Baltic J. Modern Computing, Vol. 11 (2023), No. 2, 257-271
https://doi.org/10.22364/bjmc.2023.11.2.03

Cognitive Checkup and Mental Training Platform for Elite Athletes

Eglė BUTKEVIČIŪTĖ[1], Liepa BIKULČIENĖ[2], Tomas BLAŽAUSKAS[1]
Aistė ŽEMAITYTĖ[3]

[1]Faculty of Informatics, Kaunas University of Technology, Studentu 50, Kaunas, LT-51368, Lithuania
[2]Faculty of Mathematics and Natural Sciences, Kaunas University of Technology, Studentu 50, Kaunas, LT-51368, Lithuania
[3]MB Lipsė, Raudondvario pl. 72A, LT-47182 Kaunas, Lithuania

ORCID 0000-0002-6652-2536, ORCID 0000-0002-3101-6967, ORCID 0000-0003-2858-328X, ORCID 0009-0003-8206-4111

egle.butkeviciute@ktu.lt, liepa.bikulciene@ktu.lt, tomas.blazauskas@ktu.lt, aiste.zemaityte@gmail.com

Abstract. Usually, an athlete's health condition evaluation and training plan arrangement is based on physical activity. For example, it is known that training programs should include tactical-cognitive training to improve tactical knowledge. However, together with physical health condition monitoring, professional athletes should also focus on how cognitive-mental abilities like reaction times, focus, anticipation, risk taking, etc. influence their performance in competitions. The aim of this research is to create a new evaluation and testing tool to measure athlete's cognitive abilities and prepare training that includes individualized mental exercises. This information should be provided to athletes and their coaches to improve and optimize their performance in competitions. Three different tasks were selected to evaluate cognitive abilities: concentration task, attention transfer task and anticipation task. The created testing system includes athlete's client device, sensors, and specialist client device. All tasks can be performed using athlete's client devices that support modern browsers. All three tasks evaluate an athlete's reaction time, concentration, memory, attention peculiarities, decision making skills, anticipation, and focus. The individualized mental abilities training plan was proposed based on the results obtained. A set of intelligent services that allow the continuous monitoring and smart coaching of athletes will be developed, focusing on the measurement of parameters related to the psychophysiological state and cognitive tests.

Keywords: cognitive test, mental health, web application, testing platform, personalized adaptive system.

1. Introduction

Professional sport performance depends on many physiological factors together with mental health indicators. Mental health is a state of mental well-being and the main part of overall health. It can be defined in three main characteristics – the absence of disease, physical and social environment, and cognitive abilities to fully perform functions and balance between oneself (Bhugra et al., 2013). Cognitive-mental abilities like reaction time, anticipation, risk taking, focus, etc. influence the performance of an athlete to a high extent. This is mostly noticeable while comparing high-performance athletes with novices because certain mental abilities like decision making or anticipation are much more developed in elite athletes (Kida et al., 2005; Petri et al., 2020). Another aspect that influences performance is psychophysiological parameters like heart rate variability (HRV). Usually, biofeedback and neurofeedback are integrated into self-regulation programs of athletes.

From practical experience it is known that athletes can have deficiencies in certain cognitive factors that may influence their performance. Currently there are some distinguished digital solutions for testing of these cognitive-mental abilities, but digitalized training is only available in non-professional format. The main issue is that there is no publicly available solution in digital form for testing and training cognitive-mental factors with mental training help in a meaningful definite manner, which is required for athletes. In most cases, cognitive abilities of athletes are evaluated during the individual interview and training involves meetings with sport psychologists (Larson et al., 2012). A centralized, user-friendly, and purpose-built tool would be a cost-efficient alternative to what is currently available on the market.

In this research the focus is on the creation of a checkup system of cognitive factors with mental training help. The training of these mental functions for the preparation of athletes is gaining traction worldwide. While digitalization of psychological tests is well underway with market leaders like "Vienna Test System" (Ong, 2015), that are poorly, if at all, adopted for preparation of elite athletes. This is since these companies put their product focus on the testing itself, without highlighting and training mental factors that are bottlenecking performance. There are some digital solutions for training like MPU-easy (https://www.mpu-easy.de), yet these are not tailored to athletes, for example the main goal of MPU-easy tool is to prepare persons for driving fitness examinations. Furthermore, the existing state of the art testing/BFB monitoring systems are very expensive and complicated to the average target user.

The aim of this research is to create a new technique to continuously assess athlete's fitness and health to provide information to athletes and their coaches and to help them optimize performance during competitions. The collected data will be used to combine sensing technologies, emerging IoT communication capabilities and artificial intelligence for embedded data interpretation and user analytics.

There are three main goals:

- Development of test platform in order to monitor the athlete's mental condition in testing day and in coaching process.
- Data collection and analysis – the athletes' data will be collected and then analyzed in order to assess the athlete's current state.
- Coaching and supervising algorithms will be developed to stimulate the athletes to improve their cognitive abilities.

For better understanding the entire testing and training process the user journey diagram is presented in Figure 1. Participants are adult athletes (age: 16 years old or older), who have access and can use mobile devices, that also have needs for mental evaluation and training. The planned estimated sample size of the case study is up to 50 athletes practicing in different sport fields.

In this research physiological parameters will be evaluated for athletes: ECG (HRV and LF/HF ratio). Besides the usual device athletes may use virtual reality devices that support WebVR as well. The cognitive test platform includes measurements of attention, anticipation and decision making that combine all cognitive health domains.

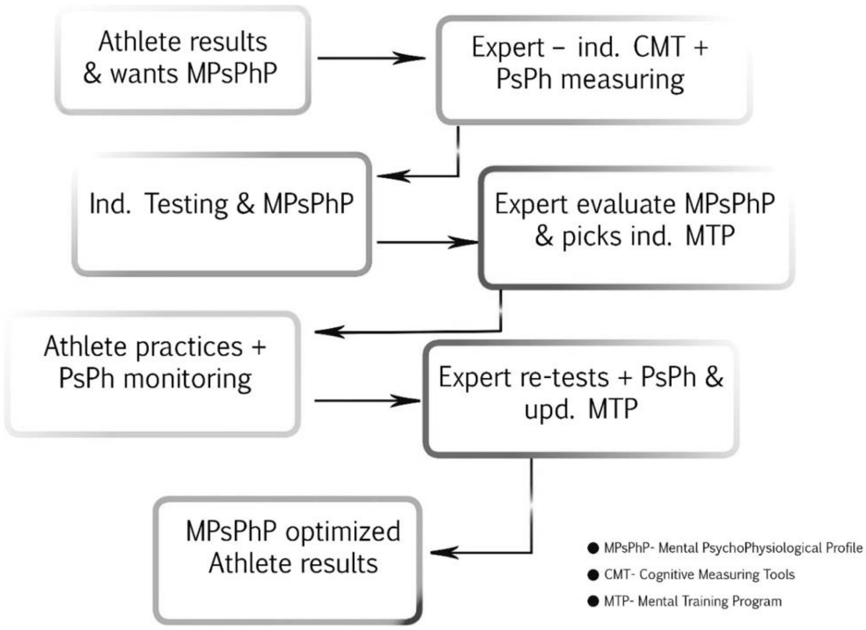


Figure 1. User journey diagram.

Collected data will be further analyzed by using classical statistical and Artificial Intelligence (AI) techniques in order to discover relation between the variables and possible classification. The main hypothesis is that this intelligent system will provide sport specialists and athletes a tool to improve athletes mental health, promote the training and supervise process to improve mental health outcomes and sport results. A set of intelligent services that allow the continuous monitoring and smart coaching of athletes will be developed, focusing on the measurement of parameters related to the psychophysiological state and cognitive tests.

2. Related work

There are many studies about how physical activity maintains and improves cognitive function and health related quality of life (Alsubaie et al., 2020). Cognitive functions include domains of perception, memory, learning, attention, decision making, and language abilities (Kiely, 2014). There are several ways to conceptualize cognitive ability domains such as by the general process involved, regional brain functions, or based on the complexity of the operations (executive functioning) (Harvey, 2019). After conducting the literature analysis on various cognitive ability factors, three main categories have been determined:

- Concentration: literature studies related to concentration focus on theoretical model where three main variables are considered: energy – the state of concentration is exhausting and drains the energy; function – the concentration function that is necessary to perform a task; and accuracy – the quality of performance (Sörqvist et al., 2016). All three variables should be considered during changes of cognitive load and increasing or decreasing distractibility.

- Attention transfer: functions that represent attention transfer part could be split into four main characteristics: selectivity (the quality of choice), transfer (to flexibly control limited computational resources), width (the performance with different task complexity), and orientation (the ability to adapt to different environment or the task) (Lindsay, 2020; Martens, 2002).
- Anticipation: the anticipation exercises evokes a multidimensional set of cognitive (include attentional, arousal, and emotional responses), somatic (the tension of muscles), and visceral adjustments (include metabolic and autonomic responses)(Koppula et al., 2022; Paridon et al., 2017).

There are various cognitive tests and scores for five cognitive health domains: verbal memory, visual memory, visual motor, reaction time and impulse control (Taylor et al., 2018). It is often assumed that cognitive impairment strongly influences the overall mental functional outcome. However, in most cases the reported associations are modest (Shames et al., 2007). Most studies that evaluate cognitive health are largely inconclusive with intricate findings in the mental health evaluation. Some studies show a decrease in cognitive function across cognitive domains (Covassin et al., 2010) while other studies lead to no difference at all (Tsushima et al., 2013). Results may be affected by various limitations in the data processing part, such as a small sample size, inaccurate analysis without considering age factor, possible injuries or concussion and recovery time, not evaluated trigger factors during evaluation process and other aspects.

The essential part in all studies is to select correct cognitive tests that could appropriately evaluate mental health or condition. The standardized cognitive tests are used as a starting point for the formal neuropsychological assessment of patients that already have complaints about their mental health (Petersen et al., 2018). However, some standardized tests have limitations in availability of translations, time constraints, copyright, etc. (Olazarán et al., 2016). Eight standardized cognitive tests (ACE-R, CERAD, CDT-Sunderlant, Memory Alteration Test, MMSE, MoCA, Qmci) were found to have similar accuracies in the detection and evaluation of mental illness. However, the low number of studies may be the factor of no statistical significance (Breton et al., 2019). Other non-standardized cognitive tests that could be found in literature are the Stroop Test, Trail-Making Test, Wechsler Digit-Span Test (Onate et al., 2000), Word List Recall, Story Recall, Digit Symbol Substitution, Digit Symbol Copy (Pearman et al., 2020), etc. Cognitive tests together with physiological data are being used in military applications (Friedl, 2018), for people with dementia (Husebo et al., 2020), to evaluate disabilities and measure cognitive performance in daily life after traumatic brain injury (Wilson et al., 2021), and other fields.

The variety of different cognitive tests complicates the comparison of different research. However, the analysis and methods are similar in most literature and usually contains basic statistical analysis (averages, standard deviation and confidence intervals estimation, hypothesis), sensitivity analysis (Gallinat and Spaulding, 2014) or exploratory factor analysis for partial mediation model constructions (Burić, 2015). Methods like cortical entropy evaluation (Liu et al., 2020), attention-based CNN method (Yin et al., 2020) or any other deep learning model uses encephalogram signals or image processing. Although using these methods a cognitive health evaluation may be accurate enough, the time complexity is inefficient. Furthermore, it may be difficult to collect EEG data in a non-clinical environment. Environmental noise, movement artifacts, blinks, sounds and other disturbances may affect the EEG signal. That is why in this research only cognitive tests and HRV analysis were used to evaluate an athlete's mental health and its improvement.

Tasks for the cognitive health evaluation in this paper are chosen based on other research and practice. For example, a cognitive test (matching symbols) is based on the "Vienna Test System" where respondents compare a geometric figure with other geometric figures. Within a certain time, respondents press different keys to identify if the figure is identical to another or not. Three fixed working time possibilities are implemented. In a short time window, the respondents react only if a figure is identical to the comparison figure. It is proven that their cognitive abilities have a major influence on an individual's performance in challenging activities like competitions. This test is being used in clinical neuropsychology, safety assessments, sports psychology, and etc. (Kiss and Balogh, 2019). Another study (Andrade et al., 2020) was focused on examination of the associations between attention and tactical behaviour efficiency. The Vienna Test System was used to assess young soccer players' attention. The Generalized Linear Models were used and showed that attention is positively associated with the tactical behaviour efficiency. This also shows that cognitive abilities and their improvements are an essential part in athletes' training process.

3. Testing and training platforms

The proposed solution was separated into two parts that were created for different purposes. The first solution (see Figure 2) is dedicated to sports specialists who can conduct in-depth examination by registering sportsman actions and physiological data from sensors.

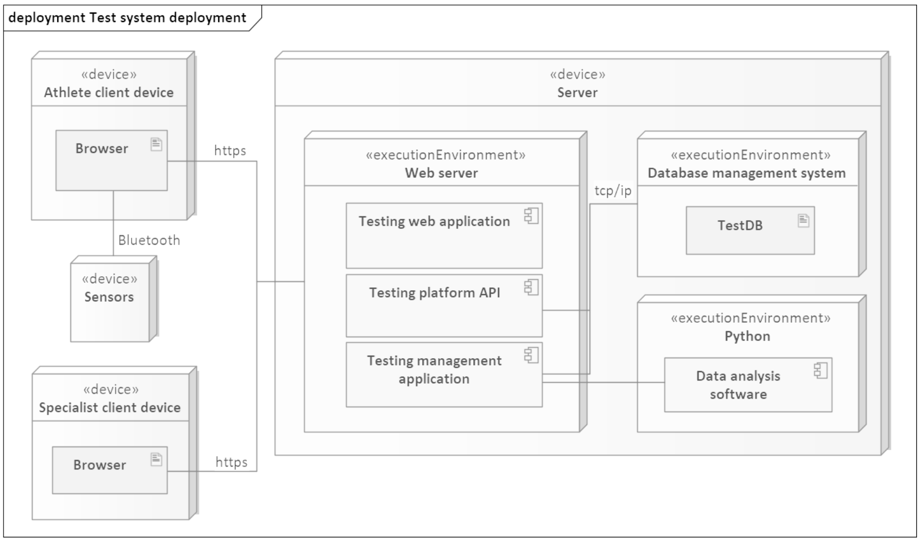


Figure 2. The structure of testing platform.

The athlete client device can be any device that supports modern browsers: personal computers, laptops, tablets, smartphones, and virtual reality devices. The testing web application starts after downloading it from the web server. The device is paired with a Polar belt h10 device using Bluetooth connection. During the session, the sportsman actions along with sensor data are transferred to the server using testing platform API. After the testing, the specialist can investigate sportsman data using a testing management application. That application is a website that uses data analysis software to calculate parameters.

The training platform (see Figure 3) is dedicated mostly for training. It doesn't require sensors and it doesn't gather physiological data. On the other hand, it is a convenient tool for everyday activities. The application is provided as a learning object. It uses a SCORM standard. Therefore, this application can be integrated in most popular learning management systems or installed locally in the sports organization servers or using cloud services. This approach was used to provide tools for learning management systems for user management, progress tracking and gamification. Also, the training information can be provided as a learning material.

The training application is installed by uploading a SCORM package into the learning management system. The athlete can access this application using a device that supports a modern browser (virtual reality devices are supported as well). The athlete performs a training session, and the application estimates a score for the performed task. This score is transmitted to the learning management system using SCORM API. Now, the specialist may use a gamified approach to visualize sportsman achievements and provide motivation and recommendations for the further training. The specialist can track sportsman progress using learning management system tools.

For our research, we use a Moodle learning management system (https://moodle.org/) and LevelUp (https://levelup.plus/) gamification plugin.

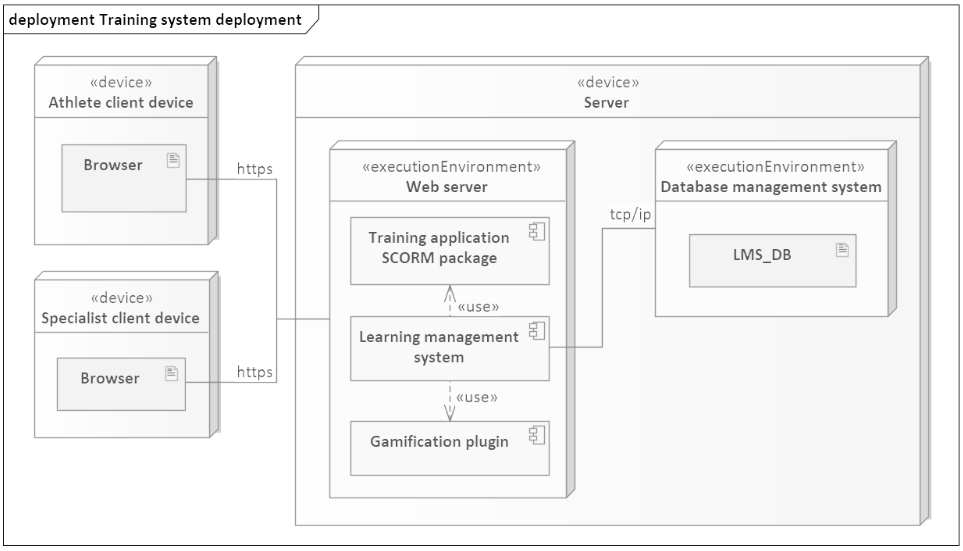


Figure 3. The structure of training platform.

The athlete application includes three different interactive tasks (anticipation task, concentration task, attention transfer task) with additional block for the HRV registration in a calm state. Testing and training may be performed in virtual reality or using a personal computer. When the program starts the login window and then the main window appears that has four options with all three interactive tasks (see Figure 4). At the beginning of the cognitive health testing process the "calm state registration" option should be selected. Time series of RR intervals are being recorded using a Polar belt h10 (3 min duration) to evaluate HR parameters before tests.

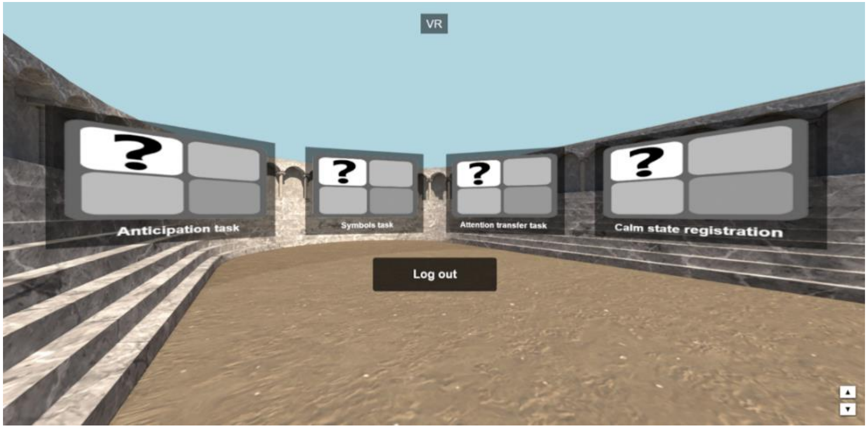


Figure 4. Visual representation of the training platform: the main window with four options.

4. Tasks description

In order to evaluate mental health all three cognitive tasks should be completed. The order is irrelevant. The participant may see results of each test at the end of the task. However, the summary or any other information is not provided. More detailed results are visible only in the specialist system. Every testing task consists of intro mode (contains task description and other important information to understand instructions), training mode (to try the task before testing) and check-up mode (for the final testing). The intro and training modes are optional. The RR signals are recorded when all three tasks are performed and used in the data analysis part where HRV is estimated and compared to registration results of the calm state.

4.1. Concentration task

The concentration task evaluates reaction time, concentration with and without stimulus. The main idea of this task is to compare one (separate) figure with 5 others that are listed below and respectively press (or select) a button if there is a match or not. An example of this task environment and obtained results is provided in Figure 5. The task is divided into three levels depending on maximum time spent to select a figure. In the first level the maximum time is 2.5 sec. The second level is harder and the maximum time in this case is 2 sec. Finally, in the hardest level a figure should be selected in 1.5 sec before images are being changed.

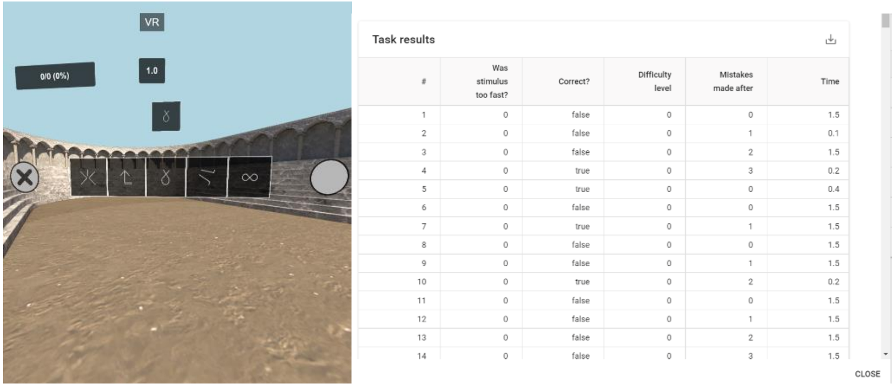


Figure 5. The basic part of the environment of the concentration task (left) and an example of obtained results in specialist systems (right).

To better understand how a participant reacts to mistakes, two additional triggers were included in this test: additional irritating sound during the task and stimulus that is too fast to react to. These triggers should also affect the HRV data. In the ideal case, if cognitive health is very good, stimulus should not affect testing results and HRV data. A bad concentration when stimulus appears may be noticed if a higher number of mistakes are made or reaction time becomes longer. Depending on the number of mistakes that were made, reaction time values and HRV results, the personalized training program will be proposed to improve cognitive abilities.

4.2. Attention transfer task

For the memory evaluation the attention transfer task was selected. It also evaluates reaction time, attention peculiarities and concentration abilities. The task consists of two parts that are consistently followed by each other during the whole task. Both parts start with a random integer number selected from 1 to 49. In the first part the previous number needs to be remembered and value plus one (+1) should be selected from the table. Meanwhile, in the second part the previous value needs to be remembered and minus one (-1) values should be selected from the table. An example of this task representation and obtained results is provided in Figure 6.

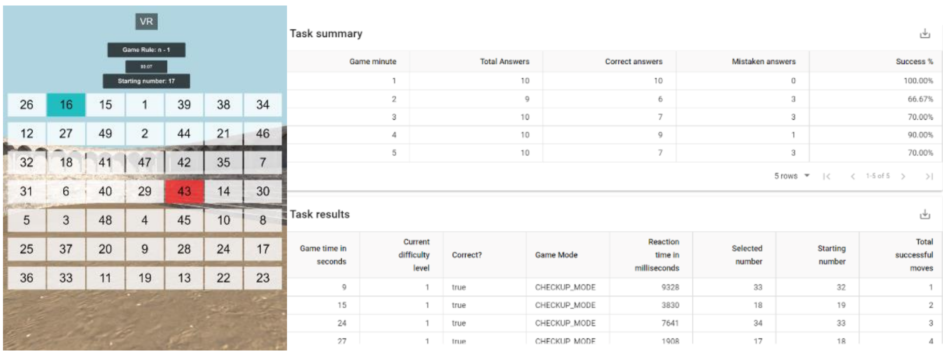
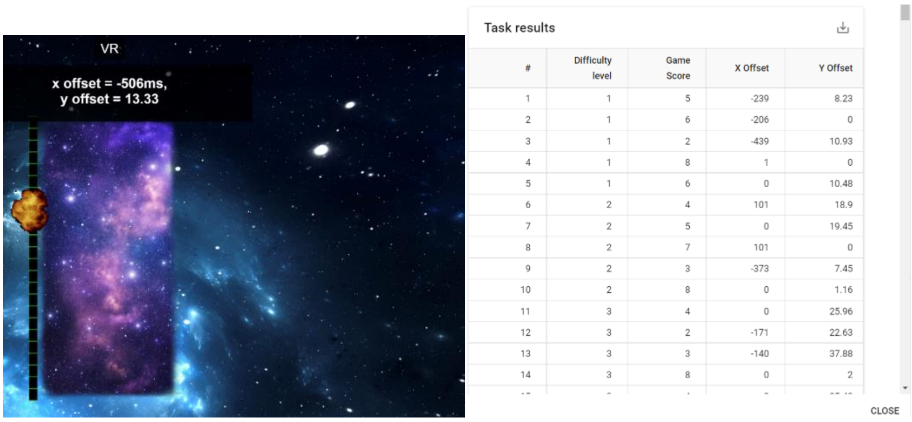


Figure 6. The basic part of the environment of the attention transfer task (left) and an example of obtained results in specialist systems (right).

4.3. Anticipation task

The anticipation task is made for evaluation of mental skills such as decision making, anticipation, reaction time and focus. The purpose of this task is to capture the accuracy of the prediction in space and time. Each set starts with the moving ball in a certain direction or trajectory. The movement continues in the invisible section. The left mouse button should be pressed when and where you believe the ball crosses the line. After the button is pressed the ball explodes and points where a ball actually was. The Figure 7 shows the example of the environment of this task (left) and obtained results in specialist systems (right).



#	Difficulty level	Game Score	X Offset	Y Offset
1	1	5	-239	8.23
2	1	6	-206	0
3	1	2	-439	10.93
4	1	8	1	0
5	1	6	0	10.48
6	2	4	101	18.9
7	2	5	0	19.45
8	2	7	101	0
9	2	3	-373	7.45
10	2	8	0	1.16
11	3	4	0	25.96
12	3	2	-171	22.63
13	3	3	-140	37.88
14	3	8	0	2

Figure 7. The basic part of the environment of the anticipation task (left) and an example of obtained results in specialist systems (right).

The attention transfer task consists of three levels: 1 - linear movement (horizontal direction); 2 - linear movement (with different angles); 3 - arc type movement (with different angles). Together with angle shifts the speed of the moving ball also varies. The results table marks not only the task scores but also the difference from the correct position in x and y axis.

5. Results and recommendations

All results are presented in the specialists system after all previously mentioned tasks (concentration, attention transfer and anticipation tasks) were completed. The example of the concentration task data analysis is presented in Figure 8. Here white circles correspond to correct answers, black - incorrect answers. In this example additional stimuli were between 15 and 25 tasks. The results have shown that for this particular athlete stimulus implies mistakes, so his concentration was relatively low. Overall results are quite bad and in the real performance athletes must react faster and be more accurate. In Figure 8 a reaction time for three levels (different time gap until next symbols sequence) is presented. In the third level results were better than in previous levels. It may be affected by the absence of stimuli and probably a participant learned and got used to the task.

Comparing values that are shown in boxplots (see Figure 8 (right)), the upper thresholds do not differ from each other and are almost the same - 1.5 s. Differences were observed only between the shortest possible response time for the least complex tasks where it reached the lowest value - 0.6 s. When the task became more complex, the reaction time increased by +0.2 s and +0.3 s (reached 0.8 s for medium difficulty levels and 0.9 s at the highest level of complexity). This allows us to select the shortest possible individualized task submission time for the different tasks in the training system for concentration development.

After analyzing the obtained values (see Figure 8) it was observed that the subject works fast and accurately in the time interval between 0.6 and 1.1 s, achieving the result of 13 out of 19 correct answers. Meanwhile the 9 out of 10 correct answers were obtained in 1.3 s, and conversely, 10 out of 13 answers were incorrect when the response time was 1.6 s. It indicates that the speed of stimulus delivery can be selected up to 1.3 s depending on its complexity. Assessing the number of correctly processed tasks the indicator of the most difficult level seems to be positive - 15 out of 20 units, followed by the number of correct answers obtained between the simplest and intermediate level - 9 out of 20 and 8 out of 20, respectively. Based on these results it is recommended to proportionally allocate an individualized exercise plan from the simplest to intermediate levels.

After analyzing athletes' errors when the concentration task was performed it was noticed that in 9 cases out of 60 (15%) the error (incorrect answer) was followed by an additional error, or even 3 errors in a row. This indicates that the athlete needs to integrate mental measurements and cognitive tasks into training sessions - attention-oriented self-talk.

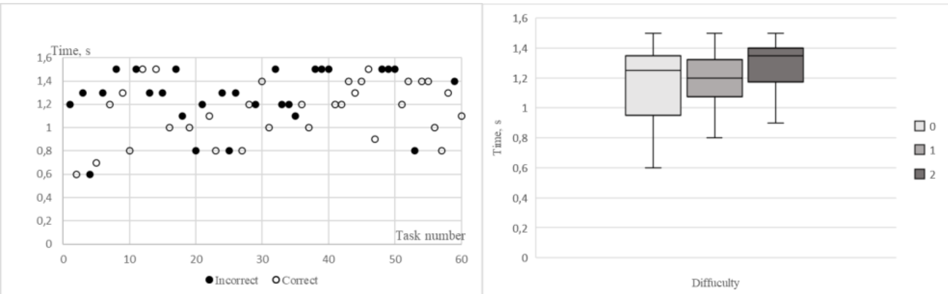


Figure 8. The results of the concentration task: reaction time of correct and incorrect answers (left) and boxplots of reaction time by difficulty (right).

The example of the attention transfer task data analysis is presented in Figure 9 and Figure 10. In the first minute 100% accuracy was reached (see Figure 9 (left)). Meanwhile the reaction time in the first minute fluctuates from 2556 ms to 6746 ms (see Figure 10 (left)) and the median is equal to 3904 ms. There are a similar number of answers in every minute (9 or 10 in each minute) (see Figure 10 (right)). Accurate results could also be seen in the 4th minute. Less scattered reaction time where values fluctuate from 2415 ms to 6103 ms shows higher stability and concentration while performing this task. In this case the median is equal to 4199 ms. Comparing median values, it could be noticed that in the 2nd minute of the task the reaction time was longest while in the 5th minute the task performance was with the shortest reaction time.

Accessing the dynamics of the attention transfer task an excellent start could be noticed. However, in the rest of the minutes the accuracy and mobilization decreases, and the anxiety increases (see Figure 10 (right)). In the preparation of the individualized training program the reaction time peculiarities should be considered together with the performance quality. This means that a 5 min duration task should be divided into 5 separate parts (5 x 1 min) with the purpose to reach 90% accuracy with at least 9 answers within each minute. Furthermore, at the beginning of the training process it is recommended to have a short break after every minute. If the goal is reached the task performing time should be extended with the proportions 2 x 2 min + 1 x 1 min and later – 1 x 3 min + 1 x 2 min. Finally, all 5 min should be performed with no resting time.

The overall athlete's performance of the task was quite good. However, the results of elite athletes must always be near 95-100 %. In this particular case an athlete must train his cognitive abilities.

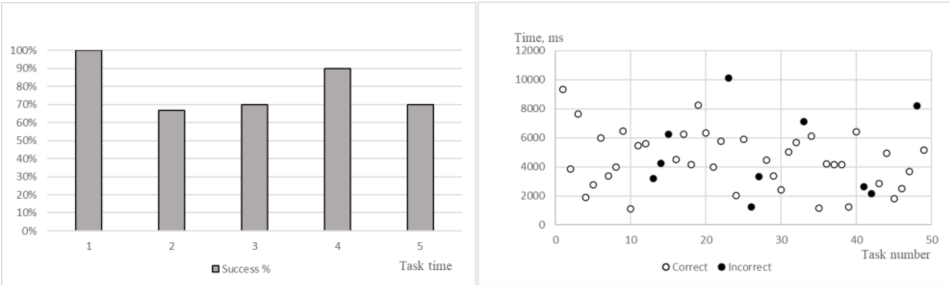


Figure 9. The results of the attention transfer task: success percentage by minutes (left) and reaction time of correct and incorrect answers (right).

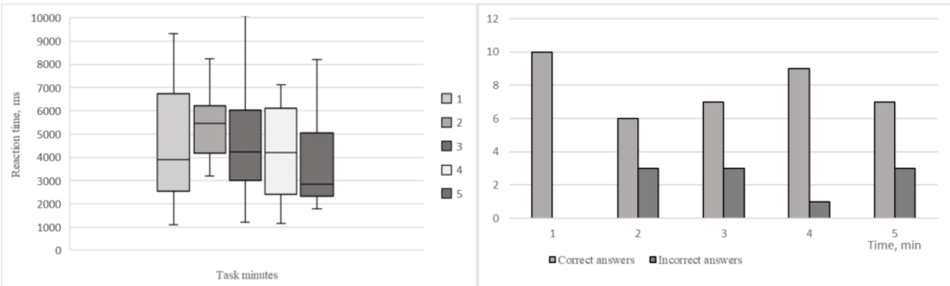


Figure 10. The results of the attention transfer task: boxplots of reaction time by minutes (left) and correct and incorrect answers by minutes (right).

The example of the anticipation task data analysis is presented in Figure 11 and Figure 12. In the evaluation of the precision of anticipation components in time and space, ideally accurate results were observed with a ratio of 8/3. It should be noted that the precision in space does not always coincide with the precision in time. This leads to the importance of the individualized cognitive training arrangement for each part separately.

Analyzing fluctuations (see Figure 11 (left)) of the time anticipation data it was noticed that early responses are more common and less accurate compared to delayed responses (interval from -400 to -150 ms versus +100 ms and 6 units compared to 2 units). Arranging individualized training plans it is recommended to include time allocation tracking tasks to improve timing tracking skills.

In the case of spatial anticipation (see Figure 11 (right)), stable and precise results were recorded at the beginning of the exercise - 3 tasks were performed sufficiently, 2 tasks were accurate. Following results fluctuated and observed values were: 2 inaccurate, 1 accurate, 1 sufficient, 1 close to accurate, 3 inaccurate, 1 close to accurate, 1 inaccurate and 1 close to accurate. Creating an individualized spatial anticipation training plan, it is recommended to insert breaks every 3 tasks at the beginning and in the second part of the training - every 2 tasks.

The lowest data variation in terms of complexity can be observed at the intermediate level. Simple tasks were performed with high accuracy with some negative exceptions. The worst results were obtained at the most difficult level. Assessing the overall accuracy in time and space, tasks 4, 10, 14 and 16 were performed perfectly, accounting for 20% of the total number of tasks. In order to optimize the athletes' anticipation ability, the goal of the training process should be to reach 30% of well-performed tasks in 2 weeks.

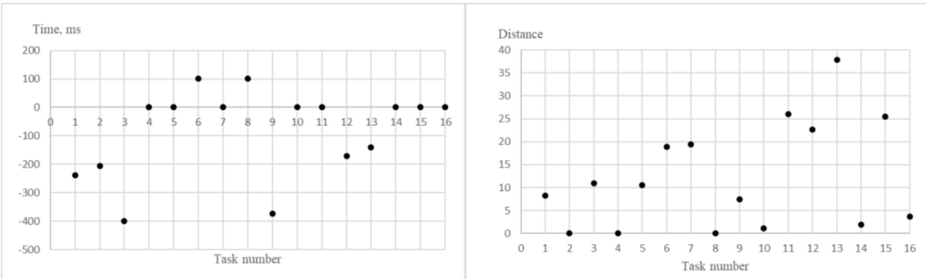


Figure 11. The results of the anticipation task: time scale anticipation (left) and space scale anticipation (right).

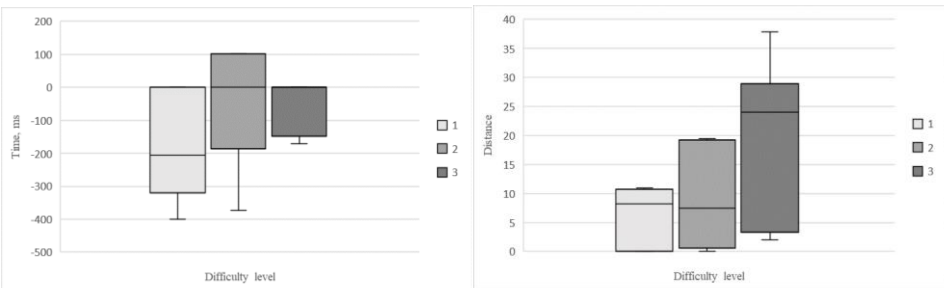


Figure 12. The results of the anticipation task: boxplots of the time scale anticipation by difficulty (left) and boxplots of the space scale anticipation by difficulty (right).

6. Conclusions

The testing and training systems were designed and created to evaluate athlete's cognitive abilities and prepare training plans. In this research three different cognitive tasks were selected: concentration task, attention transfer task and anticipation task. It was noticed that all three tasks are appropriate to evaluate an athlete's reaction time, concentration, memory, attention peculiarities, decision making skills, anticipation, and focus. The individualized mental abilities training plan was proposed based on the obtained results. It was noticed that in the concentration task stimulus implies mistakes and athletes have relatively low performance in concentration. Based on these results recommendations were applied to proportionally allocate an individualized exercise plan from the simplest to intermediate levels. The anticipation task results, and analysis were separated into two parts (time and special anticipation) because the precision in space does not always coincide with the precision in time.

The analyzed example clearly showed that the athlete is not properly trained in the cognitive health aspect. The training plan was prepared and suggested that includes concentration, attention transfer and anticipation tasks performance daily. Within two week the improvement in reaction times, focus, anticipation, risk taking, and memory were expected.

Limitations

The proposed solution includes digitalized testing and training systems of cognitive abilities evaluation and improvement for professional athletes. The created application allows to check and monitor cognitive factors with mental training help at the same platform. However, in this study other mental health factors were not included such as social or psychological problems, and others. Furthermore, only physically healthy individuals participated in this research with no medical diagnosis or visible health issues and disabilities.

It is worth mentioning that this is not a standardized system with generalized rules and representative research groups. The system is designed for the individual need to improve cognitive abilities that is based on improvements in reaction time and correct answers scale. The study does not involve specific norms or standardized solutions.

Acknowledgement

This research was funded by a grant (No. 1.2.2-MITA-K-702) from the Agency for Science, Innovation and Technology (MITA) regarding the project "Stimulate continuous monitoring in personal and physical health " ITEA-2019-19008-Inno4Health.

References

Alsubaie, S. F., Alkathiry, A. A., Abdelbasset, W. K., Nambi, G. (2020). The Physical Activity Type Most Related to Cognitive Function and Quality of Life. *BioMed Research International*. https://doi.org/10.1155/2020/8856284

Andrade, M. O. C. De, González-Víllora, S., Casanova, F., Teoldo, I. (2020). The Attention As a Key Element to Improve Tactical Behavior Efficiency of Young Soccer Players. *Revista de Psicologia Del Deporte*, *29*(2), 47–55.

Bhugra, D., Till, A., Sartorius, N. (2013). What is mental health? *International Journal of Social Psychiatry*, *February*, 2013–2015. https://doi.org/10.1177/0020764012463315

Breton, A., Casey, D., Arnaoutoglou, N. A. (2019). Cognitive tests for the detection of mild cognitive impairment (MCI), the prodromal stage of dementia: Meta-analysis of diagnostic accuracy studies. *International Journal of Geriatric Psychiatry*, *34*(2), 233–242. https://doi.org/10.1002/gps.5016

Burić, I. (2015). The role of social factors in shaping students' test emotions: a mediation analysis of cognitive appraisals. *Social Psychology of Education*, *18*(4), 785–809. https://doi.org/10.1007/s11218-015-9307-9

Covassin, T., Elbin, R. J., Nakayama, Y. (2010). Tracking neurocognitive performance following concussion in high school athletes. *Physician and Sportsmedicine*, *38*(4), 87–93. https://doi.org/10.3810/psm.2010.12.1830

Friedl, K. E. (2018). Military applications of soldier physiological monitoring. *Journal of Science and Medicine in Sport*, *21*(11), 1147–1153. https://doi.org/10.1016/j.jsams.2018.06.004

Gallinat, E., Spaulding, T. J. (2014). Differences in the Performance of Children With Specific Language Impairment and Their Typically Developing Peers on Nonverbal Cognitive Tests: A Meta-Analysis. *Journal of Speech, Language, and Hearing Research*, *57*, 1363–1382. https://doi.org/10.1044/2014_JSLHR-L-12-0363

García-González, L., Moreno, M. P., Moreno, A., Gil, A., Del Villar, F. (2013). Effectiveness of a video-feedback and questioning programme to develop cognitive expertise in sport. *PLoS ONE*, *8*(12), 1–12. https://doi.org/10.1371/journal.pone.0082270

Harvey, P. D. (2019). Domains of cognition and their assessment. *Dialogues in Clinical Neuroscience*, *21*(3), 227–237. https://doi.org/10.31887/DCNS.2019.21.3/pharvey

Husebo, B. S., Heintz, H. L., Berge, L. I., Owoyemi, P., Rahman, A. T., Vahia, I. V. (2020). Sensing technology to facilitate behavioral and psychological symptoms and to monitor treatment response in people with dementia: A systematic review. *Frontiers in Pharmacology*, *10*(February), 1–13. https://doi.org/10.3389/fphar.2019.01699

Kida, N., Oda, S., Matsumura, M. (2005). Intensive baseball practice improves the Go/Nogo reaction time, but not the simple reaction time. *Cognitive Brain Research*, *22*(2), 257–264. https://doi.org/10.1016/j.cogbrainres.2004.09.003

Kiely, K. M. (2014). Cognitive Function. In *Encyclopedia of Quality of Life and Well-Being Research* (pp. 974–978). Springer. https://doi.org/10.1007/978-94-007-0753-5_426

Kiss, B., Balogh, L. (2019). A study of key cognitive skills in handball using the vienna test system. *Journal of Physical Education and Sport*, *19*(1), 733–741. https://doi.org/10.7752/jpes.2019.01105

Koppula, A., Barra, R. R., Sridharan, K. S. (2022). Effects of exercise anticipation on cardiorespiratory coherence. *Physiological Reports*, *January*, 1–14. https://doi.org/10.14814/phy2.15381

Larson, N. C., Sherlin, L., Talley, C., Gervais, M. (2012). Integrative Approach to High-Performance Evaluation and Training: Illustrative Data of a Professional Boxer. *Journal of Neurotherapy*. https://doi.org/10.1080/10874208.2012.729473

Lindsay, G. W. (2020). Attention in Psychology , Neuroscience , and Machine Learning. *Frontiers in Computational Neuroscience*, *14*(April), 1–21. https://doi.org/10.3389/fncom.2020.00029

Liu, M., Liu, X., Hildebrandt, A., Zhou, C. (2020). Individual Cortical Entropy Profile: Test–Retest Reliability, Predictive Power for Cognitive Ability, and Neuroanatomical Foundation. *Cerebral Cortex Communications*, *1*(1), 1–17. https://doi.org/10.1093/texcom/tgaa015

Martens, P. (2002). Health transitions in a globalising world: towards more disease or sustained health? *Futures*, *34*, 635–648.

Olazarán, J., Hoyos-Alonso, M. C., del Ser, T., et al. (2016). Practical application of brief cognitive tests. *Neurología (English Edition)*, *31*(3), 183–194. https://doi.org/10.1016/j.nrleng.2015.07.005

Onate, J. A., Guskiewicz, K. M., Riemann, B. L., Prentice, W. E. (2000). A Comparison of Sideline Versus Clinical Cognitive Test Performance in Collegiate Athletes. *Journal of Athletic Training*, *35*(2), 155–160. https://doi.org/10.17615/0zeb-8x84

Ong, N. C. H. (2015). The use of the Vienna Test System in sport psychology research: A review. *International Review of Sport and Exercise Psychology*, *8*(1), 204–223. https://doi.org/10.1080/1750984X.2015.1061581

Paridon, K. N. Van, Timmis, M. A., Nevison, C. M., Bristow, M. (2017). The anticipatory stress response to sport competition; a systematic review with meta-analysis of cortisol reactivity. *BMJ Open Sport & Exercise Medicine*, 1–11. https://doi.org/10.1136/bmjsem-2017-000261

Pearman, A., Neupert, S. D., Hughes, M. L. (2020). State Anxiety Is Related to Cortisol Response During Cognitive Testing for Older Adults. *Gerontology and Geriatric Medicine*, *6*, 1–10. https://doi.org/10.1177/2333721420914776

Petersen, R. C., Lopez, O., Armstrong, M. J., et al. (2018). Practice guideline update summary: Mild cognitive impairment report of theguideline development, dissemination, and implementation. *Neurology*, *90*(3), 126–135. https://doi.org/10.1212/WNL.0000000000004826

Petri, K., Droste, M., Witte, K. (2020). Analysis of anticipatory cues in karate kumite using an in-situ-study. *Journal of Martial Arts Research*, *3*(3), 1–20. https://doi.org/10.15495/ojs

Scharfen, H. E., Memmert, D. (2019). Measurement of cognitive functions in experts and elite athletes: A meta-analytic review. *Applied Cognitive Psychology*, *33*(5), 843–860. https://doi.org/10.1002/acp.3526

Shames, J., Treger, I., Ring, H., Giaquinto, S. (2007). Return to work following traumatic brain injury: Trends and challenges. *Disability and Rehabilitation*, *29*(17), 1387–1395. https://doi.org/10.1080/09638280701315011

Sörqvist, P., Dahlström, Ö., Karlsson, T., Rönnberg, J. (2016). Concentration: The Neural Underpinnings of How Cognitive Load Shields Against Distraction. *Frontiers in Human Neuroscience*, *10*(May), 1–10. https://doi.org/10.3389/fnhum.2016.00221

Taylor, K. M., Kioumourtzoglou, M. A., Clover, J., et al. (2018). Concussion History and Cognitive Function in a Large Cohort of Adolescent Athletes. *American Journal of Sports Medicine*, *46*(13), 3262–3270. https://doi.org/10.1177/0363546518798801

Thompson, M., Hilliard, A. (2021). Developing Mental Skills in Youth Athletes. *Strategies*, *34*(3), 23–28. https://doi.org/10.1080/08924562.2021.1896920

Tsushima, W. T., Shirakawa, N., Geling, O. (2013). Neurocognitive functioning and symptom reporting of high school athletes following a single concussion. *Applied Neuropsychology: Child*, *2*(1), 13–16. https://doi.org/10.1080/09084282.2011.643967

Wilson, L., Horton, L., Kunzmann, K., Sahakian, B. J., et al. (2021). Understanding the relationship between cognitive performance and function in daily life after traumatic brain injury. *Journal of Neurology, Neurosurgery and Psychiatry*, *92*(4), 407–417. https://doi.org/10.1136/jnnp-2020-324492

Yin, Z., Chen, B., Zhen, W., Wang, C., Zhang, T. (2020). The Performance Analysis of Signal Recognition Using Attention Based CNN Method. *IEEE Access*, *8*, 214915–214922. https://doi.org/10.1109/ACCESS.2020.3038208

Received February 27, 2022, revised April 30, 2023, accepted May 11, 2023