Akdeniz Spor Bilimleri Dergisi

Mediterranean Journal of Sport Science

MJSS

ISSN 2667-5463

Kadın Serbest Dalışçılarda Dalış Antrenmanlarının Akut Dönemde Yürütücü Fonksiyonlar ile İlişkisi[1]

Gökhan TUNA

DOI: https://doi.org/10.38021asbid.1373615

ORIGINAL RESEARCH

Trakya University, Kırkpınar Faculty of Sport Science, Edirne/Turkey

Corresponding Author:
Gökhan TUNA
tunagokhan@yandex.com

Received: 09.09.2023

Accepted: 25.10.2023

Online Publishing: 29.10.2023

Öz

Farklı ortamlardaki ve farklı egzersiz türlerinin bilişsel performansa etkisi güncel merak konuları arasında yer almaktadır. Bu çalışmada da kadın profesyonel dalış sporcularının nefes tutma egzersizi sonrası yürütücü fonksiyon ve tepki süreleri değişimlerinin araştırılması amaçlanmıştır. Araştırmaya profesyonel serbest dalış branşından 7 sağlıklı kadın katılımcı dahil edilmiştir. Katılımcılara uygulanacak olan “2 N-Geri” görevinin öğretilmesi için familarizasyon oturumu, antropometrik ölçümler, maksimal nefes tutma kapasite testi, kara ve su ortamında bilişsel test skorlarının belirlenmesi için karada ve suda nefes tutma egzersiz oturumlarında ölçümler gerçekleştirilmiştir. İstatistiksel değerlendirmeler için JASP 0.16.2 programı kullanılmıştır. Verilerin analizinde tekrarlayan ölçümlerde ANOVA kullanılmıştır. Anlamlılık düzeyi $p< 0,05$ olarak belirlendi. 2 N-Geri testinin reaksiyon zamanı (RT) sonuçları değerlendirildiğinde, karada nefes tutma egzersizinden hemen sonraki reaksiyon zamanlarının ($\bar{x}$: 0,59 ± 0,14), kontrol koşulundaki reaksiyon zamanlarına ($\bar{x}$: 0,47 ± 0,10) göre anlamlı düzeyde uzadığı görülmüştür ($p<0,05$). N-Back testinin doğru yanıtları arasında ise anlamlı bir farklılık görülmemiştir ($p> 0,05$). Ayrıca, katılımcıların reaksiyon süreleri ve doğru cevap sayıları arasındaki korelasyon analizinde, su koşulundaki egzersiz sonrası reaksiyon süreleri ve doğru cevap sayıları arasında anlamlı ve güçlü bir negatif korelasyon bulunmuştur ($p<0,05$). Bu bulgular ışığında suda ve karada gerçekleştirilen nefes tutma egzersizlerinin akut olarak bilişsel fonksiyonları kontrol koşuluna kıyasla istatistiksel ılımlı düzeyde iyileştirdiği, reaksiyon sürelerinin kara koşulunda kontrol koşuluna göre anlamlı düzeyde geliştiği görülmüştür.

Anahtar kelimeler: Bilişsel Performans, Nefes Tutma Egzersizi, Dalış, Tepki Süresi, Egzersiz

The Relationship of Diving Training with Executive Functions in the Acute Period in Female Free Divers

Abstract

The effect of different types of exercise in different conditions on cognitive performance is among the current topics of interest. This study aims to investigate the changes in executive function and reaction times of female professional divers after breath holding exercises. The study involved 7 healthy female participants who were engaged in professional free diving. The training sessions included acclimatization to the '2N Back Test', anthropometric measurements, maximum breath holding test and cognitive test results in land and water settings. Statistical analyses were performed using JASP 0.16.2 Repeated measures ANOVA was used for pairwise comparisons. The significance level was set at $p<0.05$. The reaction time results of the '2 N back test' showed that the reaction times (RT) immediately after the on-shore breathing exercise ($\bar{x}$: 0.59 ± 0.14) were significantly reduced compared to the control condition ($\bar{x}$: 0.47 ± 0.10) ($p<0.05$). There was no significant difference between the accuracy of the 2 N back test ($p> 0.05$). Additionally, a significant strong negative correlation was found between reaction times and accuracy following water-based exercise ($p<0.05$). In conclusion, breath holding exercises performed in water and on land improved cognitive functions at a statistically moderate level compared to the control condition, and reaction times improved significantly in the land condition compared to the control condition.

***Keywords*:** Executive Function, Breath-Holding Exercise, Diving, Reaction Time, Exercis

[1] [1] This study was presented at the 7th International Academic Sports Research Congress.

Introduction

The physiological responses to physical activities applied under different environmental conditions have been well-documented. In the expanding literature, there has been a particular focus on the relationship between exercise and cognitive functions, especially in recent years (Mandolesi et al, 2017). Executive functions are at the center of this focus. Executive cognitive functions are defined as higher-level cognitive functions that require the control and direction of lower-level, more automatic functions, such as planning, monitoring, activating, modifying, and inhibiting (Dronkers and Baldo, 2009). The acute and chronic changes in these functions in response to exercise are being elucidated through imaging-based (Colcombe et al., 2006), neurophysiology-based (Günay et al., 2019), and cognitive test-based assessments (Manci et al., 2023). Our current understanding particularly highlights that aerobic exercise positively affects executive functions in the acute phase (Hacker et al., 2020). In the chronic period, it is known that cognitive improvement and preservation occur through brain-based structural and physiological improvements (Erickson et al., 2011).

In physical activities conducted in water, physiological changes are observed through three important factors. Firstly, the elimination of gravity and the increase in hydrostatic pressure due to the nature of water occur (Türkmen et al., 2022) .This increases cardiovascular efficiency in individuals and, functionally, augments the amount of blood returning to the heart, thereby increasing stroke volume (Pendergast et al., 2015). This circulatory change affects many physiological systems secondarily. The second factor is the temperature of the water. An increase in water temperature creates hyperthermic conditions, leading to increased fluid loss, elevated systolic blood pressure, and impaired cardiovascular performance (Proulx et al., 2003). On the other hand, as water temperatures shift toward hypothermic conditions, it results in higher glycolytic activity, impaired respiratory depth, increased basal metabolism, and other effects (Castellani & Young, 2016).The third important factor is the depth of the water. As you go deeper, thoracic pressure increases due to increased pressure, and lung volumes decrease. (Patrician et al., 2021). Additionally, due to the activation of the "diving reflex," the organism goes into standby mode, redirecting blood flow toward vital organs (Godek and Freeman, 2022). When these unique physiological responses are combined with exercise in water, they lead to the emergence of different physiological responses (Raymond and Cooper, 2022).

When we think of diving among women, Japanese AMA women come to mind. They are known for their high-frequency dives without using any equipment other than goggles and exhibit hunter-gatherer behavior, reaching depths of up to 25 meters (Sugawara et al., 2018). At the competitive level, the longest known breath-holding record for women in the water is an extreme 09:02 minutes (Wikipedia, 2023). The emergence of this physiological adaptation is a result of a longterm, regular training regimen. While many metabolic, cardiovascular, and hemodynamic processes related to the diving response have been extensively investigated, the relationship between cognitive functions and diving, especially changes related to executive functions, has been studied in only a limited number of cases (Pourhashemi et al., 2016; Sharma et al., 2023; Logie and Baddeley,1985). In these studies, the focus is on the effects of equipped, oxygen-supported SCUBA diving rather than breath-hold divers.

It is noteworthy that there is a lack of research in the literature regarding the acute cognitive responses of female diving athletes to training-induced stimuli. Particularly, the scarcity of research targeting specific populations such as female diving athletes highlights the need for further investigation. This study aims to investigate the acute effects of breath-hold training on cognitive attributes in professional female diving athletes. Our main hypothesis is that acute breath-hold exercise could enhance executive functions and reaction times in an aquatic setting compared to on-land conditions.

Method

Participants

The study comprised 7 female competitive divers with an average of 7 years' experience in diving sports (mean age 18±2.23 years, mean height 163.57±6.37 cm, mean body weight 53.42±4.72 kg). Exclusion criteria for the study included upper respiratory tract disorders, injuries, individuals not participating in regular diving training, and those within their menstrual cycle. The number of participants was determined using the G-Power 3.1.9.7 program. The effect size of the study was calculated as 0.7 based on variance analysis in the G-Power program. With a 5% alpha significance level and 85% power, the study required a minimum of 7 participants. Ethical approval for the study was granted by the Trakya University Ethics Committee under approval number TÜTF-GOBAEK 2023/248. During the current research, the "Directive on Scientific Research and Publication Ethics of Higher Education Institutions" was followed.

Experimental Design

The experiments were conducted in four sessions. During the initial visit, participants were informed and introduced to the N-Back test protocols. In the familiarization session, participants were verbally acquainted with the 2 N-Back cognitive tasks and were instructed to perform the test twice. Two days later, all participants attended the control session (CO). In this session, baseline 2 N-Back Test, anthropometric measurements and lung capacities were measured. Following a two-day interval, participants were randomly assigned to complete both the water (WA) and land sessions

(LA). Similarly, after another two-day resting period, participants completed the session they had not previously participated in. While all tests were conducted by the researcher, the design and implementation of the breath-holding protocol were carried out by a national level coach.

All sessions were scheduled between 4:00 PM and 6:00 PM. Cognitive tests were administered on the same computer model. Participants were instructed to refrain from engaging in high-intensity exercise within the last 24 hours to ensure they were adequately rested. During the water tests, the water temperature was maintained at 26-27 degrees Celsius. Participants were also requested to abstain from alcohol and caffeine consumption within the last 24 hours and to ensure proper hydration before the tests. Additionally, individuals who had slept for six hours or less during the night were included in the study on different days.

Anthropometric Measurements

Height was measured mid-breath using a portable stadiometer (Seca, model 217, Hamburg, Germany) with an accuracy of 0.5 cm. Body mass index (BMI) was determined using a calibrated electronic scale (Seca, model 875, Hamburg, Germany). Participants' weight measurements were taken barefoot by the poolside, wearing only swimwear. BMI was calculated as mass divided by height squared (mass/height^2), with body weight recorded in kilograms (kg) and height measured in meters (m) (Giles et al., 2021).

Lung Capacity Measurements

The measurements were carried out using an ultrasonic sensor-equipped Spiro Scout spirometer from Ganshorn Medizin Electronic Niederlauer, Germany (Figure 1a; Guerriero et al., 2015). All tests were conducted following the general acceptability criteria established by the European Respiratory Society (ERS, 2005) (Laursen et al., 2021; Bernhardsen, 2022). Participants were thoroughly informed about the measurement procedures. Clear instructions were provided to guide participants through the test process, and they were encouraged to follow the instructions at each stage to ensure proper breathing technique (Akpinar et al., 2006; Sim et al., 2017).

Test maneuvers were repeated at least three times in a standing position, and the highest recorded value was selected. To provide support in case of dizziness during measurements, a chair was placed behind participants (Miller et al., 2005). Only reproducible tests with less than 5% variability were considered valid. Participants were instructed to take a full inhalation to utilize their total lung capacity and then exhale through a nozzle until reaching residual volume. For forced vital capacity (FVC) measurements, participants were directed to seal their lips around the mouthpiece after taking a maximal breath and then exhale slowly and evenly until there was no change in volume

(0.025 L) for 1 second (Miller et al., 2005). Throughout all tests, participants wore a nose clip (Diniz et al., 2014; Miller et al., 2005).

Breath Hold Exercise Protocol

The protocol consists of two sessions (warm-up and breath-hold training) and is completed in approximately 40 minutes.

Warm-up Session:

Before breath-hold exercise sessions in both dry-land and aquatic environments, a 10-minute standard warm-up protocol was administered (Figure 1b).

- 30 seconds breath hold, followed by 30 seconds of breathing
- 1 minute breath hold, followed by 1 minute of breathing
- 2 minutes breath hold, followed by 2 minutes of breathing
- 1 minute breath hold, followed by 1 minute of breathing
- 30 seconds breath hold, followed by 30 seconds of breathing

Training Session:

After a 5-minutes transition period following the warm-up, breath-hold loads equivalent to 50% of participants' their official best time durations were determined (https://tssf.gov.tr/tssf-yarisma-sonuclari/). Between each repetition, a progressive load was applied consisting of 1/2 and 1/1 work/rest ratios, totaling 2 sets (4 repetitions). Participants completed this session in approximately 25 minutes. To eliminate the pressure effect, underwater applications were performed on the water's surface (Figure 1). In all conditions, muscular activity was minimized to prevent exercise-induced oxygen consumption. During the initial part of the resting phase, participants maintained a normal breathing rhythm. Prior to the shallow dive phase, they took a breath to the Total Lung Capacity, and with partial and slow exhalation, performed their final breaths (e.g., inhale deeply in 4 beats, exhale slowly in 8 beats). Hyperventilation breathing technique was completely avoided. Participants used a nose clip during both the warm-up and main exercise sessions under all conditions.

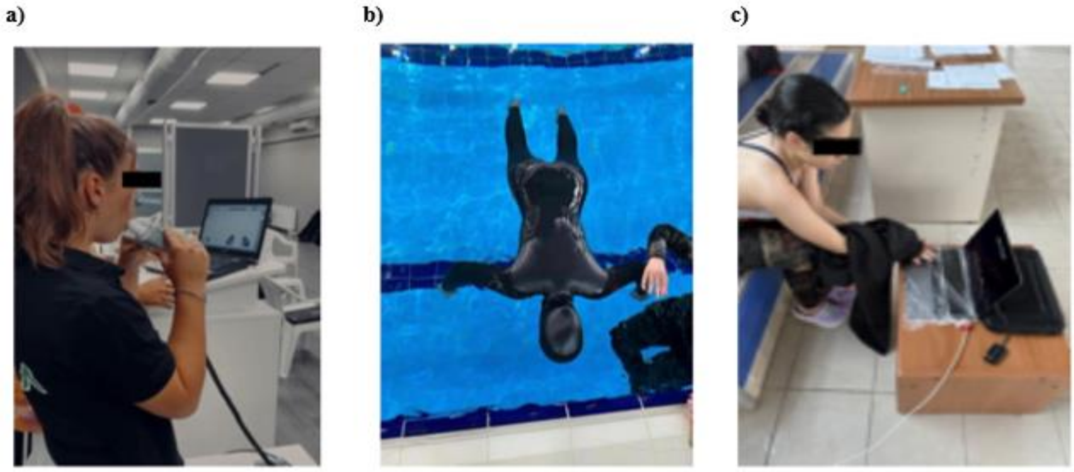

Figure 1

a) Lung Capacity Measurements, b) Breathing hold and resting position during training session, and c) Post Aquatic Hold Breathing Exercise 2 N-Back Test.

Cognitive Task Procedure

The N-Back test is a battery of tasks designed to assess working memory and inhibition (Jonides et al., 1997; Jaeggi et al., 2010). The N-Back test was written in the C programming language and implemented in OpenGL. Under all situations, participants ran the exam on a laptop. Due to the proximity of the session to a pool, a protection device was implemented in all scenarios to prevent liquid contact. The letters M,R, K, Q, H, X, B, and F were flashed in random sequence in the center of the screen during the test. If the letter on the screen matched a letter presented 'n' steps earlier, participants were directed to click a button on a response pad. The "2-Back" condition was used in this investigation. Each letter was presented on the computer screen for 500 milliseconds, with an interval of 1500 to 2000 milliseconds between each letter. All tests were completed in 5 minutes or less. Before beginning the exam, all participants went through a brief training session that consisted of a 15-letter sequence to acquaint them with the processes. Accurate response reaction times (RT) and accurate response rates (ACC%) were utilized in the study to test executive functioning. The Nexus-10 bio-amplifier, along with suitable sensors, was used to track when stimuli appeared on the screen and how participants reacted, allowing for accurate reaction times to be observed.

Statistical Analysis

JASP 0.16.2 (JASP Team, 2018; https://jasp-stats.org/, accessed on 15 Sep 2023) was used for statistical analysis and the creation of rain cloud graphics. The Shapiro-Wilk test was used to determine if the data had a normal distribution or not. Variables were normally distributed, according to the Shapiro-Wilk test results ($p<0.05$). Since the data were normally distributed, parametric tests were used. As a result, "Repeated Measures ANOVA" and “ Pearson’s Correlation Analysis” was applied. All data was presented as means (M) and standard deviations (SD). For all statistical tests, the significance threshold was set at 0.05, and effect sizes were given as partial (for ANOVA).

Findings

The study included seven female professional divers (mean age 18 ± 2.23 years, mean height 163.57 ± 6.37 cm, mean body weight 52.83 ± 4.87 kg), who trained at least 7 years. The mean forced vital capacity (FVC) values of the participants were 4.71 ± 0.37 L. and their mean official personal best maximal hold breathing values were 4.69 ± 1.04 minutes. These values are the results within the top 10 ranking in national competitions.

Table 1
Descriptive statistics of participants' cognitive test results

(n=7)	**M ± SD**
Co_2-Back Accuracy (%)	38.80 ± 0.10
Wa_2-Back Accuracy (%)	40.80 ± 0.08
La_2-Back Accuracy (%)	39.30 ± 0.13
Co_2-Back Mean Reaction Time (s)	0.47 ± 0.10
Wa_2-Back Mean Reaction Time (s)	0.52 ± 0.09
La_2-Back Mean Reaction Time (s)	0.59 ± 0.14

Table 2

Anova Analysis for three different conditions of 2-56N Back Test Accuracy and Reaction Time Results

Cases	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**	**η^2**
ACC	0.002	2	0.7972	0.227	0.801	0.036
Residuals	0.042	12	0.004			
RT	0.049	2	0.024	5.487	0.020	0.478
Residuals	0.054	12	0.004			

The accuracy results of the test compared between three different conditions showed that the conditions had no significant effect on accuracy [F (2.12)= 0.22, p> 0 .05, η2:0.036; Figure 2; Table 2).

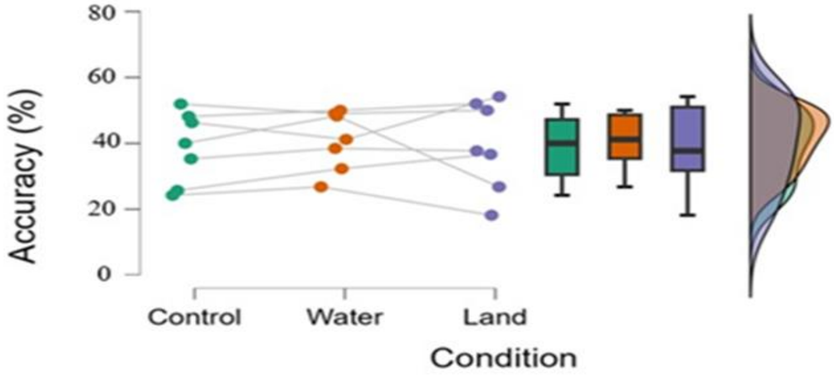

Figure 2

Participants' three different conditions 2-N Back Test Accuracy results

The comparison between three different conditions for the total reaction time results of the 2-N Back test showed there was a significant effect on the conditions [($F_{(2.12)} = 5.48$, $p = 0.020 < 0.05$, η^2: 0.478; Figure 3; Table 2). The results of pairwise comparison with the Bonferroni corrected, showed that this difference was between the land (0.59 ± 0.14) and the control condition (0.47 ± 0.10). The results showed that reaction times after breath-hold exercise sessions on land were significantly slower than the control conditions ($p = 0.020 < 0.05$).

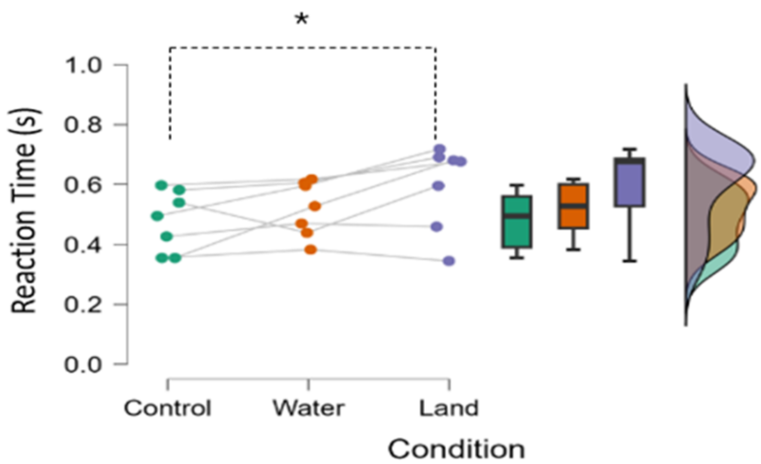

Figure 3

Participants' three different conditions 2-N Back Test reaction time results. * $p < 0.05$

Correlation Analysis

As a result of the correlation analysis between the reaction times and accuracy of the participants, a significant strong negative correlation was found between the reaction times and accuracy after exercise in water (r= -0.803, p< 0.05; Table 3).

Table 3

Pearson's Correlations Results for three different conditions of 2-56N Back Test Accuracy and Reaction Time Results

Variable		Co_N_Back_ Accuracy	Co_N_Back_ RT	Wa_N_Back_ Accuracy	Wa_N_Back _RT	La_N_Back_ Accuracy	La_N_Back _ RT
1. Co_N_Back_ Accuracy	Pearson's r	—					
	p-value	—					
2. Co_N_Back_ RT	Pearson's r	-0.346	—				
	p-value	0.447	—				
3. Wa_N_Back_ Accuracy	Pearson's r	0.902	-0.331	—			
	p-value	0.005	0.468	—			
4. Wa_N_Back_ RT	Pearson's r	-0.647	0.631	-0.803 *	—		
	p-value	0.116	0.128	0.030	—		
5. La_N_Back_ Accuracy	Pearson's r	0.790 *	-0.169	0.600	-0.197	—	
	p-value	0.034	0.717	0.154	0.672	—	
6. La_N_Back_ RT	Pearson's r	-0.790 *	0.570	-0.792 *	0.866 *	-0.538	—
	p-value	0.034	0.181	0.034	0.012	0.213	—

* p < 0.05

Discussion

The primary aim of this study is to investigate the acute effects of breath-holding exercises performed by female competitive free-diving athletes in surface water and land conditions on executive functions. The main finding of the study is a slight improvement in the number of correct responses after the exercise session in the water condition, and a significant improvement in reaction time compared to the control condition after breath-holding exercises in the land condition. Additionally, it was determined that there is a strong relationship between the number of correct responses and reaction times only in the water condition. It is known that acute exercise improves cognitive functions in clinical groups, young and elderly populations, and, of course, in athletes. Among the commonly examined cognitive functions, information processing, reaction time, memory, executive functions, and attention are noteworthy (Chang et al., 2012).

An aerobic exercise session lasting up to 30 minutes with exercise intensity between 40% and 80% has been shown to lead to improvements in cognitive and motor functions. In aquatic exercise applications, it has been reported that the influence of water, in combination with exercise, has positive effects on motor skills and cognition. One study reported that aquatic exercise is an exercise method that can enhance cognitive function and quality of life through the improvement of mental health in healthy adult women (Ayan et al., 2017). Although there are reports that merely being in the water without diving headfirst does not have a cognitive contribution, it has been reported that moderate-intensity aerobic-based swimming exercises positively affect cognitive performance (Shoemaker et al., 2019). This information forms the fundamental basis for demonstrating the 'Exercise priming' phenomenon.

In our study, the breath-holding exercise session conducted on the water surface without engaging in motor movements produced a moderate change in a manner like this phenomenon and improved the percentage of correct responses. The potential mechanisms underlying this moderate improvement may include the increased carbon dioxide levels during breath-holding at a moderate workload, which could lead to improved cerebral blood flow. Additionally, there might be a psychobiological change associated with the utilization of attentional areas related to the given task, as well as an increase in brain blood flow due to the activation of the diving reflex. Another possible mechanism could be related to the fact that breath-holding exercises in water are performed in the prone position. In this position, there is an increase in blood flow velocity in the main cerebral arteries (Lahart and Metsios, 2018). It is known that especially in women, there is a higher middle cerebral artery blood flow velocity in the prone position compared to men (Peltonen et al., 2015). The posture chosen for breath-holding (Figure 1) and the processes mentioned above during breath-holding seem to have collectively influenced the outcome.

Another notable finding of the study is the improvement in reaction time following the breath-holding exercise protocol on land. It is known that reaction time improves during the acute phases of exercise. Factors such as the speed of movements and repetition durations in exercise tasks, especially those involving motor movements, can lead to changes in reaction time. When looking at the limited number of studies on water-based exercises, it has been reported that reaction time improved in children with chronic exposure to underwater exercise (Chang et al., 2014). On the other hand, it has been reported that reaction time improved after only a 20-minute treading water swimming session (Shoemaker et al., 2019). However, responses in diving appear to be in the opposite direction. A study reporting a deterioration in reaction time after a single 20-minute SCUBA diving session (Pourhashemi et al., 2016) suggests that different activities performed in water may yield different results. In our study, while there was no improvement in reaction time during the breath-holding exercise session on the water surface, the significant differences found in the land session are in line with the information presented above. It is known that hypercapnia resulting from breath-holding increases cerebral blood flow velocity (Prakash et al., 2014). During this process, it is possible for an improvement to occur due to the increase in cerebral blood flow. Additionally, participants may have heightened their mental activity levels and arousal by focusing on task goals and engaging motivational factors to complete the task during breath-holding. With all these processes mentioned above, reaction performance may have significantly improved in the land condition.

Limitation

Although the inclusion of only 7 participants in the study seems to have a suggestive effect on the results obtained, the small population of 'elite' female freediving athletes and their relatively similar performance levels are thought to eliminate this potential limiting factor.

Conclusion

Considering the findings, breath-holding exercise sessions conducted in water and on land produce different responses in female free-diving athletes compared to the control condition. The presence of a slight improvement in executive functions in the water session and an improvement in reaction time in the land session suggests that breath-holding exercises may have different effects on cognitive functions depending on environmental conditions. On the other hand, considering the physiological changes resulting from the applied protocol, this load did not appear to have a disruptive effect on female competitive diving athletes. We believe that this information will be important in determining the training loads of female free-diving athletes and anticipating underwater risks related to cognitive function impairment. Future research should focus on experimental studies designed with different breath-holding loads, depths, and large participant groups.

Ethics Committee Permission Information

Ethical review board: Trakya University Faculty of Medicine Deannity Non Interventional Scientific Research Ethics Board Edirne, Turkey

Date of the ethical assessment document: 28.08.2023

Number of the ethical assessment certificate: TÜTF- GOBAEK 2023/ 248

Declaration of Contribution Rates of Researchers

The entire research was carried out by the sole author of the study.

Conflict Statement

The author has no conflict statement regarding the research.

Acknowledgement Statement

We would like to thank the female freediving athletes who participated in this study and their coaches for their support.

Thanks to Doç. Dr. Erkan Günay for contributing to the preparation of the article.

References

Akpinar-Elci, M., Fedan, K. B., & Enright, P. L. (2006). FEV6 as a surrogate for FVC in detecting airways obstruction and restriction in the workplace. *European Respiratory Journal, 27*(2), 374-377

Ayán, C., Carvalho, P., Varela, S., & Cancela, J. M. (2017). Effects of water-based exercise training on the cognitive function and quality of life of healthy adult women. *Journal of Physical Activity and Health, 14*(11), 899-904

Bernhardsen, G. P., Stang, J., Halvorsen, T., & Stensrud, T. (2022). Differences in lung function, bronchial hyperresponsiveness and respiratory health between elite athletes competing in different sports. *European Journal of Sport Science*, *1*-10

Chang, Y. K., Hung, C. L., Huang, C. J., Hatfield, B. D., & Hung, T. M. (2014). Effects of an aquatic exercise program on inhibitory control in children with ADHD: a preliminary study. *Archives of Clinical Neuropsychology*, *29*(3), 217-223.

Castellani, J. W., & Young, A. J. (2016). Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure. *Autonomic Neuroscience*, 196, 63-74

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., ... & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *61*(11), 1166-1170

Diniz, C. M. P., Farias, T. L., Pereira, M. C. A., Pires, C. B. R., Gonçalves, L. S. L., Coertjens, P. C., & Coertjens, M. (2014). Chronic adaptations of lung function in breath-hold diving fishermen. *International Journal of Occupational Medicine and Environmental Health*, *27*, 216-223

Dronkers, N., & Baldo, J. (2009). Encyclopedia of neuroscience (Vol. 2). *L. R. Squire (Ed.). Amsterdam, The Netherlands: Elsevier*

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., ... & Kramer, A. F. (2011). Exercise training increases the size of the hippocampus and improves memory. *Proceedings of the national academy of sciences*, *108*(7), 3017-3022

Giles, D., Barnes, K., Taylor, N., Chidley, C., Chidley, J., Mitchell, J., ... & España-Romero, V. (2021). Anthropometry and performance characteristics of recreational advanced to elite female rock climbers. *Journal of Sports Sciences, 39*(1), 48-56

Godek, D., & Freeman, A. M. (2021). Physiology, Diving Reflex. 2020 Sep 29. StatPearls [Internet]. Treasure Island (FL): *StatPearls Publishing*

Guerriero, M., Caminati, M., Viegi, G., Senna, G., Cesana, G., & Pomari, C. (2015). COPD prevalence in a north-eastern Italian general population. *Respiratory Medicine*, *109*(8), 1040-1047

Günay, E., Güdücü, Ç., & Bediz, C. Ş. (2019). How does isometric exercise affect the haemodynamics of the brain?. Neurol. Sci. *Neurophysiol*, *36*, 33-37

Hacker, S., Banzer, W., Vogt, L., & Engeroff, T. (2020). Acute effects of aerobic exercise on cognitive attention and memory performance: An investigation on duration-based dose-response relations and the impact of increased arousal levels. *Journal of Clinical Medicine*, *9*(5), 1380

Jaeggi, S. M., Studer-Luethi, B., Buschkuehl, M., Su, Y. F., Jonides, J., & Perrig, W. J. (2010). The relationship between n-back performance and matrix reasoning—implications for training and transfer. *Intelligence*, *38*(6), 625-635.

Lahart, I. M., & Metsios, G. S. (2018). Chronic physiological effects of swim training interventions in non-elite swimmers: a systematic review and meta-analysis. *Sports medicine*, *48*, 337-359.

Laveneziana, P., Albuquerque, A., Aliverti, A., Babb, T., Barreiro, E., Dres, M., ... & Verges, S. (2019). ERS statement on respiratory muscle testing at rest and during exercise. *European Respiratory Journal, 53*(6)

Laursen, C. B., Clive, A., Hallifax, R., Pietersen, P. I., Asciak, R., Davidsen, J. R., ... & Maskell, N. (2021). European Respiratory Society statement on thoracic ultrasound. *European Respiratory Journal*, *57*(3)

Logie, R. H., & Baddeley, A. D. (1985). Cognitive performance during simulated deep-sea diving. *Ergonomics*, *28*(5), 731-746

Mancı, E., Günay, E., Güdücü, Ç., Herold, F., & Bediz, C. Ş. (2023). The Effect of the Playing Positions in Basketball on Measures of Cognitive Performance. *Journal of Cognitive Enhancement*, 1-12

Mandolesi, L., Gelfo, F., Serra, L., Montuori, S., Polverino, A., Curcio, G., & Sorrentino, G. (2017). Environmental factors promoting neural plasticity: insights from animal and human studies. *Neural plasticity*, 2017

Miller, M. R., Crapo, R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., ... & Wanger, J. A. T. S. (2005). General considerations for lung function testing. *European Respiratory Journal*, *26*(1), 153-161

Patrician, A., Dujić, Ž., Spajić, B., Drviš, I., & Ainslie, P. N. (2021). Breath-hold diving–the physiology of diving deep and returning. *Frontiers in physiology*, *12,* 639377

Peltonen, G. L., Harrell, J. W., Rousseau, C. L., Ernst, B. S., Marino, M. L., Crain, M. K., & Schrage, W. G. (2015). Cerebrovascular regulation in men and women: stimulus-specific role of cyclooxygenase. *Physiological Reports*, *3*(7), e12451

Pendergast, D. R., Moon, R. E., Krasney, J. J., Held, H. E., & Zamparo, P. (2015). Human physiology in an aquatic environment. *Compr Physiol*, *5*(4), 1705-50

Pourhashemi, S. F., Sahraei, H., Meftahi, G. H., Hatef, B., & Gholipour, B. (2016). The effect of 20 minutes scuba diving on cognitive function of professional scuba divers. *Asian journal of sports medicine*, *7*(3)

Prakash, K., Chandran, D. S., Khadgawat, R., Jaryal, A. K., & Deepak, K. K. (2014). Correction for blood pressure improves correlation between cerebrovascular reactivity assessed by breath holding and 6% CO2 breathing. *Journal of Stroke and Cerebrovascular Diseases*, *23*(4), 630-635

Proulx, C. I., Ducharme, M. B., & Kenny, G. P. (2003). Effect of water temperature on cooling efficiency during hyperthermia in humans. *Journal of Applied Physiology*, *94*(4), 1317-1323

Raymond, K. A., & Cooper, J. S. (2017). Scuba Diving Physiology

Sim, Y. S., Lee, J. H., Lee, W. Y., Suh, D. I., Oh, Y. M., Yoon, J. S., ... & Chang, J. H. (2017). Spirometry and bronchodilator test. *Tuberculosis and Respiratory Diseases*, *80*(2), 105-112

Sharma, R. I., Marcinkowska, A. B., Mankowska, N. D., Waśkow, M., Kot, J., & Winklewski, P. J. (2023). *Cognitive Functions in Scuba, Technical and Saturation Diving. Biology*, *12*(2), 229

Shoemaker, L. N., Wilson, L. C., Lucas, S. J., Machado, L., Thomas, K. N., & Cotter, J. D. (2019). Swimming-related effects on cerebrovascular and cognitive function. *Physiological reports*, *7*(20), e14247

Sugawara, J., Tomoto, T., Lin, H. F., Chen, C. H., & Tanaka, H. (2018). Aortic reservoir function of Japanese female pearl divers. *Journal of Applied Physiology*, *125*(12), 1901-1905.

Türkmen, D. , Güdücü, Ç. , Bediz, C. & Günay, E. (2022). Cerebral Blood Flow and Metabolism During Vertical Immersion and In-Water Exercise. *Journal of Basic and Clinical Health Sciences* , *6* (2) , 682-688 . DOI: 10.30621/jbachs.1057262

Wikipedia (2023, 7th October). *Static apnea*, https://en.wikipedia.org/wiki/Static_apnea (07.09.2023)

This paper is licensed under a **Creative Commons Attribution 4.0 International License.**