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Investigation of Working Memory Responses in Recreational Athletes Using Virtual Reality Assessment System

Göksen ÇINAR[1], Adil Deniz DURU[2]

Abstract

Aim: This study was designed to evaluate the relationship between N-Back, a valid working memory task frequently used in cognitive psychology research, and a more ecological working memory measurement tool designed for VR, and the differences in terms of athlete performance.
Methods: N-Back (verbal and visual) and VR-ATC tasks were applied to 20 recreational and 20 sedentary individuals with consistent age and education levels. VR-ATC tasks include different tasks delivered on a total of 4 screens. The N-Back task used visual-spatial and auditory-verbal stimuli at three difficulty levels (1-back, 2-back, 3-back) as WM validation. The relationship between the results obtained from VR-ATC and N-Back scores was evaluated with the Spearman Correlation test, and the results of the athlete groups from these tests were evaluated with the Mann-Whitney U test. Statistical significance level was accepted as $p<0.05$.
Results: Spearman correlation revealed a moderate-low significant negative correlation between Verbal WM Capacity from VR-ATC and verbal N-Back 1 errors ($r=-0.377$; $p=0.017$) and impulsive errors ($r=-0.379$; $p=0.016$). Mann-Whitney U test indicated that recreational athletes performed significantly better in Verbal WM Capacity- Item Number ($U=116.0$, $p=0.023$), Verbal WM Capacity-Retention ($U=96.0$, $p=0.004$), and WM Efficiency-Task Switching Speed ($U=105.0$, $p=0.009$) compared to sedentary individuals.
Conclusion: Although there are many studies evaluating the cognitive performance of athletes with traditional or computer-based tests, they have limitations because they do not reflect daily life functions. Our study showed that an ecological working memory task, that is, a working memory task that is more integrated with daily life, better separates groups of athletes, even though it is related to traditional tasks. In this sense, VR-ATC can be considered as an alternative approach to assess athlete performances.

Keywords
Virtual reality,
Recreation,
Working memory.

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Rekreasyonel Atletlerde Sanal Gerçeklik Değerlendirme Sistemi Kullanılarak Çalışma Belleği Tepkilerinin Araştırılması

Özet

Amaç: Bu çalışma bilişsel psikoloji araştırmalarında sıklıkla kullanılan geçerli bir çalışma belleği görevi olan N-Back ile VR için tasarlanmış daha ekolojik bir çalışma belleği ölçüm aracı arasındaki ilişkiyi ve atlet performansları açısından farklarını değerlendirmek için hazırlanmıştır.
Yöntem: Yaş ve eğitim düzeyi tutarlı 20 rekreasyonel ve 20 sedanter atlete N-Back (sözel ve görsel) ile VR-ATC görevleri uygulanmıştır. VR-ATC 4 ekrandan farklı görevlere sahiptir. N-Back görevi, WM doğrulaması olarak üç zorluk seviyesinde (1-back, 2-back, 3-back) görsel-uzamsal ve işitsel-sözel uyaranlar kullanmıştır. VR-ATC'den elde edilen sonuçlar ile N-Back skorları arasındaki ilişki Spearman Korelasyon testi, atlet gruplarının bu testlerden aldığı sonuçlar ise Mann-Whitney U testi ile değerlendirilmiştir. İstatistiksel anlamlılık düzeyi $p<0,05$ olarak kabul edilmiştir.
Bulgular: Spearman korelasyonu, VR-ATC'den elde edilen Sözel WM Kapasitesi ile sözel N-Back 1 hataları ($r=-0.377$; $p=0.017$) ve dürtüsel hatalar ($r=-0.379$; $p=0.016$) arasında orta-düşük düzeyde anlamlı negatif korelasyon olduğunu ortaya koymuştur. Mann-Whitney U testi, rekreasyonel sporcuların Sözel WM Kapasitesi- Madde Sayısı ($U=116.0$, $p=0.023$), Sözel WM Kapasitesi- Akılda Tutma ($U=96.0$, $p=0.004$) ve WM Verimliliği- Görev Değiştirme Hızında ($U=105.0$, $p=0.009$) sedanter bireylere kıyasla anlamlı derecede daha iyi performans gösterdiğini ortaya koymuştur.
Sonuç: Atletlerin bilişsel performanslarını geleneksel veya bilgisayar tabanlı testler ile değerlendiren çalışmalar fazla olsa da günlük yaşam işlevlerini yansıtmadığı için sınırlılıklara sahiptir. Araştırmamız ekolojik yani günlük yaşam ile daha entegre olan bir çalışma belleği görevinin geleneksel görevler ile ilişkili olsa da atlet gruplarını daha iyi ayırdığını göstermiştir. Bu anlamda, VR-ATC atlet performanslarını değerlendirmede alternatif bir yaklaşım olarak düşünülebilir.

Anahtar Kelimeler
Sanal gerçeklik,
Rekreasyon,
Çalışma belleği.

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[1] ***Responsible Author:*** Marmara University, Institute of Health Sciences, goksencinar@gmail.com
[2] Marmara University, Institute of Health Sciences, deniz.duru@marmara.edu.tr

INTRODUCTION

The importance of sports activities has increased as the inadequacy of physical activity in daily life has become evident. Therefore, group fitness, sports clubs, and recreational sports activities have started to replace inadequate physical activity. In recent years, there has been an increase in the number of studies on the benefits of these activities (Henchy, 2011; Vella & Swann, 2021). The benefits of recreational sports can be both social, such as fostering a sense of community and increasing interaction, and psychological and educational, such as reducing stress, promoting a healthy lifestyle, improving physical strength, and enhancing academic performance (Ayhan, 2022 & Önen, 2023). Currently, the focus of most health and sport research is on the assessment of motivation, well-being and academic performance of recreational athletes. However, subjective questionnaires such as "perceived benefit" (Lower et al., 2013), rather than objective measurement methods, are used for these evaluations. Sport health research has focused on the medical effects of recreational sport (Faria et al., 2020; Morentin et al., 2021), neglecting cognitive effects.

Over the past two decades, the number of studies indicating that regular physical exercise has a positive effect on cognitive performance has increased. These studies highlight the particularly beneficial effect of physical exercise on fundamental cognitive functions such as attention and working memory (Hillman et al., 2008). Working memory (WM) is especially important in clinical, social, and educational contexts. WM affects more complex cognitive behaviors such as understanding, reasoning, and problem-solving. WM can also be considered as a capacity that is influenced by individual differences and interpreted as a variance of different skills (Engle, 2002). In the context of sports and health research, studies have evaluated WM development for assessing the development of skills such as motor learning, skill acquisition, implicit/explicit learning, imagery, and performing under pressure (Scharfen and Memmert, 2019). However, these studies are currently insufficient in measuring the contents specified in Baddeley's model of visual-spatial and phonological binding, which is also used in clinical and educational settings (Baddeley, 2003). For example, in their comprehensive study with high participation rates on elite athletes, Vaughan and Laborde evaluated only the verbal component of WM, while the visual components were not investigated (Vaughan and Laborde, 2021). In addition to the inadequacy of multiple WM measurement methods, another important limitation of traditional cognitive function measurement methods is their failure to reflect daily life.

The problems encountered in multiple cognitive assessments and the fact that cognitive tasks do not reflect daily life have brought virtual reality (VR) technology to the forefront of neuropsychology. VR provides the opportunity for individuals to interact with objects and environments in a virtual setting and manipulate them. When clinicians conduct cognitive assessments in an environment that accurately reflects real-world functions, they are able to observe and examine more accurately (Rizzo et al., 2004). In virtual reality tasks, stimulus intensity can be controlled and the effect of these stimuli on a person's performance can be measured, providing clinicians with an environment that allows for a better understanding of overall cognitive functioning. With its characteristics, VR provides a measurement opportunity with higher ecological validity (Parsey & Schmitter-Edgecombe, 2013). In contrast, traditional neuropsychological tests frequently used today are conducted in a two-dimensional environment, devoid of the stimulus richness of real life and in isolated environments, allowing for less data to be collected on a person's performance over a longer period (Chaytor and Schmitter-Edgecombe, 2003; Howieson, 2019). Measurements conducted with VR can be adapted to different populations and environments based on their needs and abilities (Wouters et al., 2014). Like other digital systems, VR also offers various advantages such as being objective, standardized, and free from human errors and biases during the scoring and interpretation process (Gould et al., 2020). In other words the shortcomings of existing research, this study hypothesizes that VR-based WM tasks have more ecological validity and better reflect cognitive performance in everyday life.

The aim of this study is to evaluate the differences between the WM task prepared in the VR environment and the N-Back task, which is frequently used in research for the same purpose, in recreational and sedentary individuals. The first hypothesis of this study is to evaluate whether VR-based WM tasks yield consistent results with traditional N-Back tasks. The second hypothesis is that the VR-based task will provide higher ecological validity compared to N-Back, better revealing the differences in cognitive performance between recreational and sedentary individuals. In this way, both the consistency of the research of a VR task designed for this purpose with a reliable test and the differences in the WM performances of people who do recreational activities compared to those who do not will be evaluated.

METHOD

Model of the research

This research was designed as cross-sectional. There are two groups to be studied: recreational and sedentary individuals. Both the VR experience and the validation task is applied to these two groups at the same time. Within the scope of the research, the relationship between VR outputs and validation task results and the distribution of these results among research groups are evaluated.

Study group of the research

The study included 40 participants aged between 24 and 46 years. This comprised of 20 recreational athletes and 20 participants in a demographically similar sedentary group. The mean age of all athletes was 36.17±6.13 years. The mean age of recreational athletes ($\bar{X}$=36.15; S.D.=6.40) and sedentary individuals ($\bar{X}$=36.20; S.D.=6.00) was found to be similar when evaluating their distribution according to groups. 32.5% of the participants were female (N=13) and 67.5% were male (N=27). All participants who volunteered for the study signed an informed consent form. This study was approved by Marmara University Faculty of Medicine Clinical Research Ethics Committee with number 09.2022.606.

Participants in the study were classified as sedentary if they had not engaged in physical activity in the last six months, and as recreational if they engaged in regular physical activity for at least 150 minutes per week over three days. People were excluded from the study if they had hearing or visual impairments that would prevent them from participating, physical disabilities, use of neuropsychiatric medications that could affect cognitive activity, or a history of head trauma, stroke, or brain surgery.

Data collection tools of the research

Apparatus: The primary hardware includes sensors and displays for immersion. NORA VRx™ - Core uses HTC Vive Pro Eye HMD with Dual OLED displays (1440 x 1600 pixels per eye), 90 Hz refresh rate, 110-degree FOV, and 615 ppi. Tobii eye tracking sensors (120 Hz sampling, accuracy 0.5°-1.1°) are integrated, calibrated per user. Interaction is via two HTC Vive controllers. NORA VRx™ - Core software employs C++, C#, Net Core V3, NetStandard v2.01, Universal Windows Platform, and Python. Tested on Intel® Core™ i9-12900K, 32GB DDR5 3200 MHz RAM, NVIDIA GeForce RTX™ 3080.

Virtual Reality Experience: NORA VRx™ - Core includes two phases. The familiarisation phase and the air traffic control (VR-ATC) phase, which includes cognitive measurement. The familiarization phase (as shown in Figure1)lasts approximately 10-15 minutes and is designed to help participants adapt to the VR environment and become familiar with the controllers.

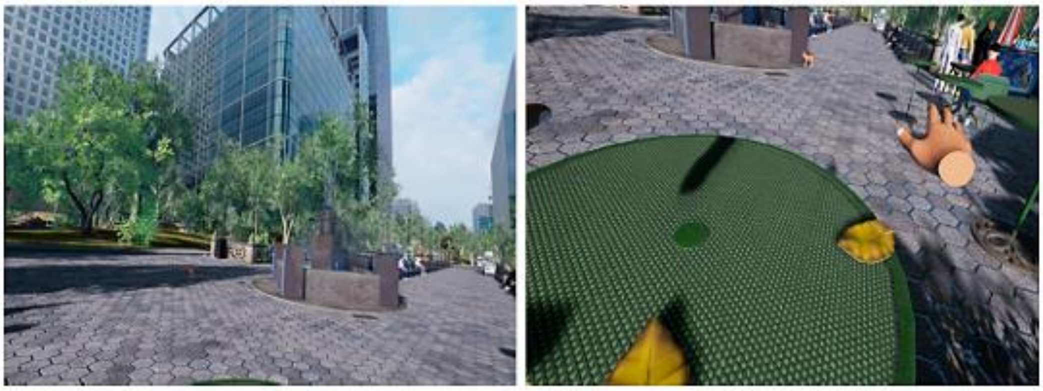

Figure 1. Familiarization phase of VR experience

Following the familiarization phase, participants begin the VR-ATC experience, where they work as air traffic controllers. This phase lasts approximately 20 minutes. The VR-ATC experience consists of a tutorial phase and six assessment phases that increase in difficulty. During the tutorial phase, participants are presented with informative text panels and an audio track to become familiar with the tasks. Each task is practiced with the aid of these panels. The cognitive assessment includes attention, information processing, and WM tasks, which are presented with different displays as shown in Figure 2.

Figure 2. Cognitive assessment phase of VR experience (VR-ATC)

The experience involves four tasks displayed on different screens, with occasional power cuts between tasks requiring participants to lift a lever to restore electricity (Figure 2). Task A involves granting landing permission to planes based on their fuel levels, with increasing numbers of planes as the task progresses. Task B asks participants to solve two math problems and select the one with the lower value, with difficulty increasing over time. In Task C, participants must identify a plane that stays in its initial position on a radar screen after it temporarily turns off and on, with more planes added as levels advance. Task D requires participants to find a target plane among similar distractors displayed on the screen.

In VR-ATC, behavioural outputs consist of the choices made in the given tasks and fixation data collected by the eye-tracking device integrated into the VR headset, as well as the time spent on the tasks. The calculations for these outputs are specific to WM and are as follows:

- *Verbal WM Capacity- Item Number:* Calculated by entering the order of the planes shown in airborne screen (Behavioral).
- *Verbal WM Capacity – Retention:* Whether the information learned in airborne screen is retained correctly after distractor tasks and the effect of the time spent in this stage on this (Behavioral & Eye-Tracking).
- *Visuospatial WM Capacity- Item Number:* Calculated by taking into account the responses given on the screen to the changes detected in the aircraft shown in radar screen (Behavioral).
- *Visuospatial WM Capacity – Retention:* Whether the information learned in radar screen is retained correctly after distractor tasks and the effect of the time spent in this stage on this (Behavioral & Eye-Tracking).
- *WM Efficiency- Task Switching Speed:* Calculated by how long it takes to adapt to the next task after completing the given task on each screen (all screens in the experience are used) (Behavioral & Eye-Tracking).

N-Back: In this task, which was used as WM validation, visual-spatial and auditory-verbal materials were used as stimuli. The task was used at three levels of difficulty (1-back, 2-back, and 3-back), administered as single tasks (for task details see Jaeggi et al., 2010). Scores calculated from the N-Back task are given below (Snodgrass& Corwin, 1988; Jaeggi et al., 2010):

- Total number of correct answers (TRUE) and the ratio of the number of correct answers to the total answers (TRUE_rate) from the 1-back, 2-back, and 3-back tasks.
- The total number of errors (FALSE) made in the 1-back, 2-back, and 3-back tasks and the ratio of the number of errors to the total answers (FALSE_rate).
- Number of failures to choose correct answers (MISS) and the ratio of the number of failures to total answers (MISS_rate) in 1-back, 2-back, and 3-back tasks.
- Responding to irrelevant stimulus (impulse_false)
- Reaction times of correct (TRUE_RT) and incorrect answers (FALSE_RT)
- Average of reaction times (RT_mean).

Data analysis of the research

Since the data were not distributed normally, non-parametric tests were used to compare the recreational and sedentary athlete groups. To test the first hypothesis, the correlation between the results obtained from the VR task and the numerical results obtained from N-Back was examined using the Spearman test. To test the differences between the groups in the second hypothesis, the Mann-Whitney U test was applied. P values below 0.05 were considered significant.

FINDINGS

Table 1. Descriptive results

Variables		n		%	
		Recreational	Sedantary	Recreational	Sedantary
Gender	Male	14	13	35.0	32.5
	Female	6	7	15.0	17.5
Education	Undergraduate	16	18	40.0	45.0
	Graduate	4	2	10.0	5.0
Total		20	20	50	50

Descriptive statistics were conducted on 40 athletes included in the study. Among recreational athletes, 30% were female (n=6) and 70% were male (n=14). Among sedentary athletes, 65% were male (n=13) and 35% were female (n=7). When the whole study population was evaluated, male recreational athletes were 35% and female recreational athletes were 15%. Male sedentary was 32.5% and female sedentary was 17.5%. Among recreational athletes, 80% were undergraduate (n=16) and 20% were graduate (n=4). In sedentary athletes, 80% were undergraduate (n=18) and 20% were graduate (n=2). When the whole study population was evaluated, undergraduate recreational athletes were 40% and graduate recreational athletes were 10%. Undergraduate sedentary was 45% and graduate sedentary was 5% (Table 1).

Table 2. Correlation results between VR-ATC WM variables and N-Back verbal subtest variables

Variables		1	2	3	4	5
Verbal 1	TRUE	0.138	0.032	0.141	0.148	0.174
	TRUE_rate	0.140	0.031	0.144	0.159	0.187
	FALSE	**-0.377***	-0.277	-0.201	-0.139	**-0.335***
	FALSE_rate	**-0.382***	-0.283	-0.200	-0.134	**-0.334***
	MISS	-0.138	-0.032	-0.141	-0.148	-0.174
	MISS_rate	-0.136	-0.032	-0.138	-0.139	-0.168
	impulsive	-0.229	-0.146	-0.146	-0.132	-0.257
	impul_false	**-0.379***	-0.279	-0.202	-0.140	**-0.336***
	TRUE_RT	0.001	-0.041	-0.027	-0.043	0.126
	FALSE_RT	0.216	0.300	0.215	0.266	0.056
	RT_mean	0.021	0.038	0.046	0.045	0.214
Verbal 2	TRUE	0.070	0.017	0.120	0.153	0.090
	TRUE_rate	0.070	0.017	0.120	0.153	0.090
	FALSE	-0.232	-0.263	-0.035	-0.071	-0.274
	FALSE_rate	-0.232	-0.263	-0.035	-0.071	-0.274
	MISS	-0.070	-0.017	-0.120	-0.153	-0.090
	MISS_rate	-0.070	-0.017	-0.120	-0.153	-0.090
	impulsive	-0.214	-0.115	**-0.315***	-0.298	-0.240
	impul_false	-0.234	-0.258	-0.051	-0.080	-0.282
	TRUE_RT	0.048	0.112	-0.060	0.031	0.133
	FALSE_RT	-0.230	-0.190	0.145	0.061	0.054
	RT_mean	-0.094	0.020	-0.030	-0.007	0.118
Verbal 3	TRUE	-0.032	-0.044	0.169	0.168	0.040
	TRUE_rate	-0.024	-0.065	0.171	0.176	-0.008
	FALSE	-0.096	-0.125	0.300	**0.366***	-0.020
	FALSE_rate	-0.081	-0.129	0.308	**0.372***	-0.031
	MISS	0.032	0.044	-0.169	-0.168	-0.040
	MISS_rate	0.041	0.019	-0.145	-0.151	-0.084
	impulsive	-0.093	-0.075	0.099	0.074	-0.159
	impul_false	-0.088	-0.112	0.306	**0.366***	-0.025
	TRUE_RT	-0.028	0.064	-0.041	0.046	0.257
	FALSE_RT	-0.015	-0.076	0.213	0.249	0.309
	RT_mean	0.012	0.072	0.059	0.144	0.262

**p<0.05; SpearmanCorrelation, 1=Verbal WM Capacity – Item Number, 2=Verbal WM Capacity- Retention, 3=Visuospatial WM Capacity – Item Number, 4=Visuospatial Working MemoryCapacity- Retention, 5=WM Efficiency – Task Switching Speed*

Both verbal and visual N-Back tasks and VR-ATC were administered to all athletes. Non-parametric Spearman correlation was applied as the results obtained from these tasks did not fit the normal distribution. A negative and moderate-low significant correlation was found between the Verbal WM Capacity- Item Number outcomes obtained from VR-ATC and the number of verbal N-Back 1 (Verbal 1) errors ($r_{verbal\ 1-\ FALSE}$=-0.377; p=0.017), the ratio of the number of errors to the whole score ($r_{verbal\ 1-\ FALSE\_rate}$=-0.382; p=0.015) and the number of impulsive errors ($r_{verbal\ 1-\ impul\_false}$=-0.379; p=0.016). A moderate-low significant negative correlation was found between Visuospatial WM Capacity- Item Number and verbal N-Back 2 (verbal 2) impulsivity rate ($r_{verbal\ 2\ -\ impulsive}$=-0.315; p=0.048). A moderate-low significant positive relationship was observed between the results of Visuospatial WM Capacity-Retention and the number of errors ($r_{verbal\ 3\ -\ FALSE}$=0.366; p=0.018), the ratio of the number of errors to the whole score ($r_{verbal\ 3\ -\ FALSE\_rate}$=0.372; p=0.020) and the number of impulsive errors ($r_{verbal\ 3\ -\ imul\_false}$=0.366; p=0.018) of Verbal N-Back 3 (Verbal 3) (Table 2).

Table 2 also shows a negative and moderate-low significant relationship was observed between the WM Efficiency- Task Switching Speed outputs of VR-ATC and the number of verbal N-Back 1 (Verbal 1) errors ($r_{verbal\ 1-\ FALSE}$=-0.335; p=0.035), the ratio of the number of errors to the whole score ($r_{verbal\ 1-\ FALSE\_rate}$=-0.334; p=0.035) and the number of impulsive errors ($r_{verbal\ 1-\ impul\_false}$=-0.336; p=0.034), similar to Verbal WM Capacity- Item Number. No significant correlation was found between the VR-ATC outputs of the athletes and the visual N-Back tasks (p>0.05).

Table 3. Distribution of VR-ATC outputs between groups

Variables	Recreational (n=20) (Mean ± Sd)	Sedantary (n=20) (Mean ± Sd)	U	Z	p
VerbalWMCapacity–ItemNumber	3.64 ± 1.29	2.76 ±0.80	116.0	-2.272	***0.023****
VerbalWMCapacity-Retention	34544.04 ± 12687.29	25286.07 ± 6965.98	96.0	-2.813	***0.004****
VisuospatialWMCapacity–ItemNumber	1.02 ± 0.49	0.70 ± 0.16	129.0	-1.922	0.056
VisuospatialWMCapacity-Retention	7618.38 ± 3404.76	5540.22 ± 1316.44	129.0	-1.921	0.056
WMEfficiency–TaskSwitchingSpeed	3928.44 ± 1131.00	3001.40 ±640.88	105.0	-2.570	***0.009****

**p<0.05; U: Mann-Whitney U test*

Since continuous data did not comply with normal distribution, Mann-Whitney U test was applied to compare the scores of recreational and sedentary individuals from VR-ATC and N-Back tasks. According to Table 3, it was seen that the Verbal WM Capacity- Item Number (U=116.0, p=0.023), Verbal WM Capacity-Retention (U=96.0, p=0.004) and WM Efficiency-Task Switching Speed (U=105.0, p=0.009) outputs were significantly distributed between the groups. It was observed that recreational athletes exhibited higher performance in all significant scores.

Table 4. Distribution of N-Back scores between groups

Variables		Recreational (n=20) (Mean ± Sd)	Sedantary (n=20) (Mean ± Sd)	U	Z	p
Verbal 1	FALSE	1.95 ±6.01	2.85 ± 4.95	132.0	-2.050	0.068
	FALSE_rate	150.00 ± 462.53	218.20 ± 381.39	132.5	-2.034	0.068
	impul_false	1.95 ±6.01	3.05 ± 5.48	132.0	-2.050	0.068
Verbal 2	impulsive	0.050 ± 0.22	0.15 ± 0.48	189.5	-0.622	0.779
Verbal 3	FALSE	5.30 ± 4.99	4.75 ± 3.99	193.5	-0.177	0.862
	FALSE_rate	376.92 ± 380.42	334.61 ± 284.59	198.0	-0.054	0.968
	impul_false	5.55 ± 5.14	5.00 ± 4.44	191.5	-0.231	0.820

**p<0.05; U: Mann-Whitney U test*

Table 4 shows the distribution of N-Back scores, which have a significant correlation with VR-ATC outcomes, between groups. Unlike VR-ATC results, none of the N-Back results were significantly distributed between groups (p>0.05).

DISCUSSION

The VR-ATC is designed to assess basic cognitive functions, particularly WM, in everyday settings. Previous studies have demonstrated that immersive and ecological VR experiences increase the likelihood that an individual's performance will align with real-life situations (Mannan et al., 2023). The objective of this study was to assess the concurrent validity of WM performances measured in VR-ATC with the N-Back test and their distribution across different groups of athletes.

In the concurrent validity assessment, WM algorithms developed on the VR-ATC axis were found to be associated with verbal WM, but not with visuospatial WM, all repetitions of the N-Back test. Existing literature on VR has shown that N-Back tasks are used to evaluate the effect of cognitive load and stress, rather than to evaluate the relationship between WM performance (Martens et al., 2019). However, cognitive assessment products designed for VR have been found to measure basic attention, episodic memory, or inhibition skills, rather than WM (Negut et al., 2016). In virtual reality experiences purported to assess WM performance, the majority of comparisons were made with newly designed computer-aided products. In this sense, our study represents a pioneering approach, as it was conducted with the N-Back task, which is employed in event-related potentials (ERPs) or functional near-infrared spectometry (fNIRS) studies and has demonstrated significant results with WM (Aksoy et al., 2021; Porffy et al., 2022).

The most significant finding of the study was that the discrepancies in athlete performance were observed in VR-ATC results, not in N-Back scores. In VR-ATC, it was determined that recreational athletes demonstrated superior retention (p=0.023), retrieval (p=0.004) and switching between multiple tasks (p=0.009) of verbal working memory tasks compared to sedentary individuals. There is a body of research indicating that individuals who engage in recreational activities for an extended period of time exhibit low stress levels and high educational performance (Ayhan, 2022& Önen, 2023). These studies suggest that their overall cognitive performance may also be high. However, the present study is the first to demonstrate the impact of recreational activities on cognitive performance.

Although the VR task is mostly visual, the correlation results were not significant in this area. There is also a disagreement on this issue at the literature level. The literature on the neuroanatomical basis of working memory functions is extensive but varied and somewhat inconsistent. For example, while our research group consistently identified distinct neural networks for verbal and visuospatial components of working memory, other studies using the less process-specific N-back task did not find such domain-specific organization (Zilles et al., 2016). Behavioral research has also revealed differences in how verbal and visual working memory are processed, though the conditions that expose these modality differences are complex. Some studies suggest inherent biases, while others show that these biases can be easily triggered by slight modifications to the task. Despite ongoing investigations into the exact nature of these modality-specific differences, the overall findings suggest that verbal and visual stimuli are represented differently in visual working memory (VWM) (Crottaz-Herbette et al., 2004).

Working memory is the most integrated of the cognitive faculties into daily life, as it involves multiple processing skills (Baddeley, 2003). When evaluated in this context, the fact that the effect of recreational activities is seen in the VR-ATC task, which is ecologically valid and immersive, rather than in the N-Back task performed at the computer, supports the existing literature and our main hypothesis.

RESULTS

According to the results of the research, the results obtained by all athletes in the WM measurement tasks given in the VR design and the scores obtained in all verbal tasks of the N-Back task (N-Back Verbal 1, 2 & 3) included the errors made, the ratio of errors to all answers and impulsive errors. A association was seen between the scores. The distribution of N-Back and VR-ATC results, which showed a association, among athlete groups was evaluated. It was observed that N-Back tasks did not separate the groups significantly. In addition, it was observed that the results of Verbal WM Capacity-Item Number, Verbal WM Capacity- Retention and WM Efficiency- Task Switching Speed obtained from VR-ATC tasks separated the groups significantly. Accordingly, it has been observed that recreational athletes process multiple verbal stimuli, retrieve multiple data, and switch between different tasks at a higher rate than sedentary individuals.

SUGGESTIONS

The most important limitation of the research is that the athlete grouping is based on participant statements. Although similar studies (Heppe et al., 2016; Brick, et al., 2020) have shown that recreational and sedentary activities are determined according to personal declaration, the lack of a numerical value to be used in research on the quality of recreational activities may have limited the measurements. Another limitation is the small number of participants. It is thought that a future study in which recreational activities are defined and a larger number of participants will be useful in evaluating the current outcomes. As a further step in the research process, it would be beneficial to assess the relationship between VR-ATC and neurological structures such as N-Back.Nevertheless, our research is important in terms of evaluating WM tasks prepared in a VR environment and in a routine experimental environment among athlete groups.

Ethical Approval Permission Information
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