Bayram *et al. BMC Sports Science, Medicine and Rehabilitation* (2025) 17:163
https://doi.org/10.1186/s13102-025-01220-4

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

Open Access

Integration of the wingate anaerobic test into a virtual reality- based evaluation system

Gulay Aras Bayram[1*], Gizem Ergezen Sahin[1], Gizem Yilmaz[1], Umut Islam Tayboga[1], Ayten Gunes Celik[2], Yasin Yildirim[3], Pinar Kaya Saribas[1] and Devrim Tarakci[4]

Abstract

Background With the advancement of technology, it is considered an important step to transfer assessment methods to the virtual environment as it provides individuals with the opportunity for equal feedback, improves test performance and allows for testing with maximum participation. The aim of this study was to evaluate the effects and differences between the classic Wingate Anaerobic Test (WAnT) and a virtual reality-based Wingate Test (VR-WAnT) on the test performance of athletes and to investigate their applicability to athletes.

Methods Thirty male athletes aged between 18 and 25 years from professional football teams were included in the study. The athletes' age, height, weight, total years of sport experience, scores on the system usability scale and satisfaction with the two different testing methods were assessed. A scenario covering all phases of the WAnT and requiring no external cues was prepared by the project team and integrated into the virtual reality headset. Athletes were first assessed using the classic WAnT in a controlled laboratory environment, and two days later the same athletes were assessed using the VR-WAnT in the same environment. Maximum power, minimum power, average power and fatigue index data from the test system were recorded for analysis.

Results The results of the study showed no statistically significant differences in maximum power, minimum power, average power and fatigue index values between the two methods ($p > 0.05$). However, according to the satisfaction measurement, the results of the VR-WAnT were statistically significantly higher compared to the classic WAnT ($p = 0.026$).

Conclusions VR-WAnT may be considered a promising alternative for anaerobic performance testing due to its potential to enhance user experience and satisfaction. It is also believed that the test may offer greater comfort for both practitioner and athletes, while introducing a novel dimension to physiotherapy and rehabilitation assessment processes.

Trial registration NCT06661395 (Registration Date: 24 Oct 2024).

Keywords Anaerobic performance, Evaluation, Football player, Virtual reality, Wingate test

*Correspondence:
Gulay Aras Bayram
garas@medipol.edu.tr
[1]Faculty of Health Sciences, Physiotherapy and Rehabilitation, Istanbul Medipol University, Beykoz, Istanbul 34810, Turkey
[2]Vocational School of Social Sciences, Sports Management, Istanbul Medipol University, Istanbul, Turkey
[3]Faculty of Health Sciences, Physiotherapy and Rehabilitation, Istanbul Gedik University, Istanbul, Turkey
[4]Faculty of Health Sciences, Ergotherapy, Istanbul Medipol University, Istanbul, Turkey

Background

In the domain of sports, particularly those involving high-intensity efforts such as sprinting and jumping, it is imperative to accurately assess anaerobic power in athletes [1]. Despite the plethora of methods and tests proposed for the measurement of anaerobic components, the 30-second Wingate Anaerobic Test (WAnT) is widely regarded as the gold standard [2]. This test involves the participants pedalling at maximum speed for 30 s on a Monark-type cycle ergometer, against a resistance equivalent to 7.5% of their body mass, while being provided with strong verbal encouragement.The performance components of the WAnT that are commonly accepted are as follows: peak power, minimum power, average power, and fatigue index [3].

It is well-documented that external visual, auditory, and tactile stimuli can enhance an individual's test performance, leading to maximal effort during the test.Studies have shown that verbal feedback provided to elite rugby players results in increased peak power and speed values in the upper body [4]. Therefore, it can be concluded that feedback or verbal encouragement given to the athlete or patient during an assessment may influence the test outcome. In circumstances where optimal performance is anticipated, external stimuli, such as musical cues, assume a pivotal role in activating performance. Empirical evidence suggests that heart rate, breathing, movement speed, and pulse tend to synchronize with the rhythm of the music [5]. While the underlying mechanisms remain to be fully elucidated, existing literature demonstrates that listening to music during the WAnT can physiologically enhance anaerobic exercise performance [6]. While previous studies have demonstrated the ergogenic effects of isolated sensory stimuli such as music and verbal cues, VR provides a fundamentally different context by integrating these stimuli into a cohesive and interactive environment. The current literature remains limited in systematically examining how immersive VR environments influence the validity, reliability, and motivational aspects of standardized anaerobic performance tests such as the WAnT. Therefore, our study aims to address this specific gap by comparing the VR-WAnT with the traditional WAnT protocol.

Virtual reality (VR) is defined as a three-dimensional graphical representation of real or imaginary environments, created by a computer, in which individuals can interact with and feel immersed. VR applications utilise a combination of visual, auditory, and tactile stimuli to provide participants with motivating and enriched environments for training. The virtual environment provides feedback to enhance motor learning and allows individuals to explore their surroundings independently and safely during high-intensity training protocols, thereby increasing their sense of autonomy [7]. The impact of VR can be so profound that it elicits responses comparable to those observed during exposure to real-life scenarios. Furthermore, the experience of being inside an avatar, where the individual perceives the avatar's actions as their own brain's intention, can engender a sense of ownership over the actions [8].

In the contemporary context, VR applications have emerged as a prevalent and efficacious modality within the domain of rehabilitation. A substantial body of research has demonstrated the efficacy of VR applications in addressing a wide range of physical and psychological health concerns, including upper and lower extremity disorders, balance and gait issues, cognitive disorders, pain management, and the prevention of kinesiophobia [9, 10]. The integration of VR into treatment programs offers numerous advantages, including the reduction of dependency on time and place, the provision of detailed feedback on performance, ease of use, affordability, and reliability, the facilitation of multiple repetitions of activities, the stimulation of motor learning and cortical plasticity, the support of social interaction, and the enhancement of cognitive functions [11, 12].

However, it is noteworthy that VR applications, which are commonly used in rehabilitation, have not found equal representation in assessment processes. The integration of VR scenarios, accompanied by auditory and visual feedback, is purported to enhance the uniformity of evaluations and ensure reproducibility. Furthermore, these methods could ensure that verbal and auditory feedback provided to participants during the assessment is consistent. In this context, it is anticipated that VR-based scenarios will introduce a new dimension to athletes' evaluation processes. The present study aims to investigate the impact and differences in performance between a traditional WAnT application and a VR-WAnT with a head-mounted display, and to assess its applicability in athletes.

Methods

Participants

The sample size for the study was calculated using the G*Power (version 3.0.10; Universitat Düsseldorf) program with 90% power and an effect size of 0.55, utilizing the "t tests-difference between two dependent means (matched pairs)" design ($\alpha = 0.05$, $\beta = 0.95$), resulting in 30 athletes.

The present study was conducted with male athletes, representing two professional football teams, on a voluntary basis. Initially, 47 athletes were considered for participation in the study; however, 17 were excluded for various reasons, including injury, failure to attend the second measurement, and exceeding the time interval between the two tests. The 30 athletes were provided with written and verbal information, and their signed consent was obtained (Fig. 1). Participants were required to be aged between 18 and 25 years, to have volunteered for participation, and to have successfully completed the WAnT test independently prior to the commencement of the study. Participants with a history of hospitalization for a duration exceeding two weeks within the previous three months, a history of acute illness or injury during the study period, or who had not participated in training activities for a period of two weeks were excluded from the study.

Procedures

In this study, a scenario developed by the researchers for WAnT was constructed in such a manner that no external cues were provided. Subsequently, the scenario was converted into software by procuring services from expert engineers in the field and integrated into the VR headset. Consequently, a preliminary trial of the scenario was undertaken, and enhancements were implemented in accordance with the deficiencies and errors that were identified during this phase. The final version of the scenario was then subjected to a series of tests, the results of which indicated that the application was both effective and accurate [13]. This iterative process of development and refinement has contributed to enhancing both the efficacy of the application and the user experience. The full version of the developed test scenario was uploaded to ClinicalTrials.gov (NCT06661395).

All athletes included in the study were initially evaluated using the traditional WAnT method in a controlled laboratory environment under similar conditions (15:00–17:00). Subsequent to a two-day interval, the same athletes performed the VR-WAnT under the same conditions. The experimental apparatus employed was a Monark-type cycle ergometer (Monark, Stockholm, Sweden), with seat adjustment and distance between handlebars and crank customized for each athlete. During the tests, the laboratory temperature was maintained at 18 °C, with humidity levels ranging from 40 to 50%, and efforts were made to minimize noise and external distractions. Prior to the assessment, athletes were instructed to abstain from training or competitive activities and to fast for a minimum of two hours.

Classic wingate anaerobic test (WAnT)

The classic Wingate Anaerobic Test (WAnT) is a test that consists of a 7-minute warm-up period followed by a 30-second test phase. During the warm-up, the athlete performed 5 min of dynamic exercises before commencing the test. Subsequently, the athlete engaged in a standardized 5-minute warm-up on the bicycle at 100 watts, during which two 2–3 s sprints were performed during the 3rd and 4th minutes. Following this, the athlete pedalled at minimal resistance (10–20 rpm) for recovery.

Following a 2-minute recovery phase, the athlete initiated pedalling for the test phase. Upon attaining the maximum pedalling rate, a weight equivalent to 7.5% of the athlete's body mass was instantaneously applied to the bicycle wheel via a lever. For the subsequent 30 s, the subject was instructed to pedal at the highest possible cadence while seated, with strong verbal motivational support. The test concluded after 30 s. Following the conclusion of the test, the athlete was instructed to rest in a seated position [14].

Virtual reality Headset-Integrated wingate anaerobic test (VR-WAnT)

All athletes who had completed the classic WAnT performed the VR-WAnT under the same conditions in the laboratory two days later. The steps of the test were identical to the previous test. The Wingate test scenario, devised by the researchers, was constructed in such a manner that no external cues were provided, with services being procured from engineers for the integration of the test scenario into the VR headset. Participants completed the test with guidance from the scenarios displayed in the virtual reality headset. The Oculus Meta Quest 2, a head-mounted display, was utilized for this study. Following the donning of the headsets, participants were able to see only the created virtual environment, and the device was connected to a computer that generated the virtual reality environment (Fig. 2).

During the warm-up phase of the VR-WAnT, athletes were presented with a virtual reality simulation in which they could be seen riding a bicycle through a forest, pedalling at a speed of 60–80 rpm for a period of 5 min (Fig. 3). In the final 3 s of the 3rd and 4th minutes, the subjects were presented with a visual of themselves positioned on a railway track, accompanied by a simulated train approaching at high speed. In response to the on-screen prompts (Hurry up!), the participants initiated 2–3 s sprints (120–160 rpm) in an attempt to evade the oncoming train. Following this, the screen displayed "Slow Down!" cues, which signalled to the athletes that they should return to their normal pace of 60 rpm revolutions per minute (Fig. 4). Following the completion of the 5-minute warm-up period, the athletes were instructed to pedal at minimal resistance (10–20 rpm) for 2 min to recover from any fatigue during the warm-up, as indicated by the "Slow down a lot!" cue on the screen, and to arrive at the race course.

Upon reaching the designated location, the athletes viewed themselves at the starting line of a bike race, accompanied by their competitors, all in a state of readiness. While in this ready position, the device automatically applied resistance, and a countdown from three began, followed by the sound of starting pistols. When the count reached zero, a flag signal indicated the

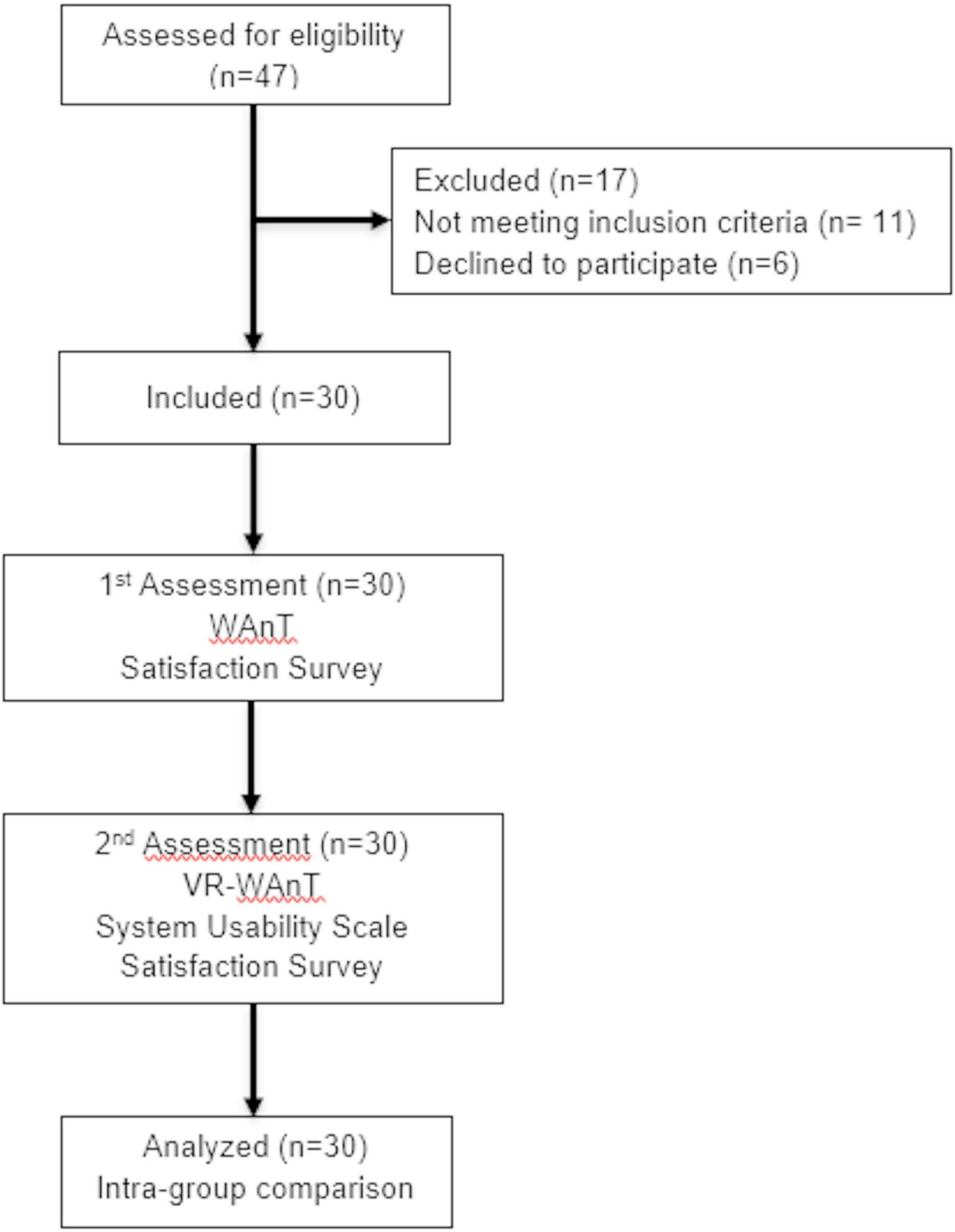

Fig. 1 Participant flow chart

Fig. 2 Virtual reality headset-integrated WAnT

Fig. 3 Warm-up phase of the VR-WanT

Fig. 4 Sprint and slow down phases in the last 3 s of the 3rd and 4th minutes

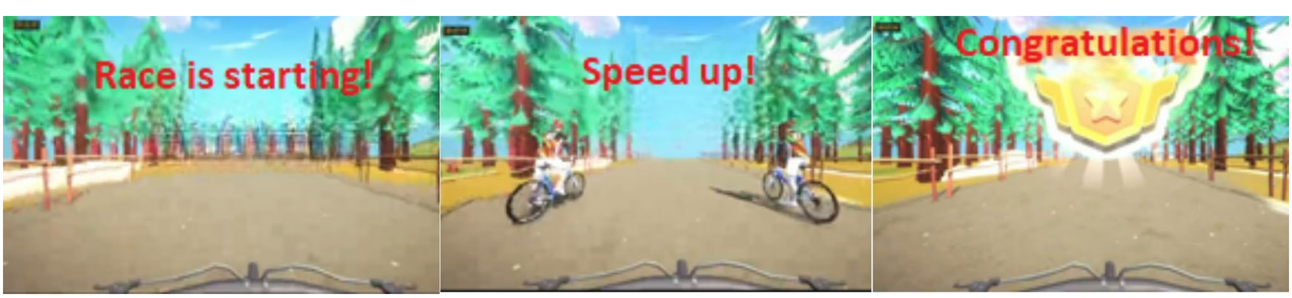

Fig. 5 Race stage

commencement of the race. Thereafter, the athletes were required to pedal at maximum effort in a seated position for a duration of 30 s, with the objective of surpassing their competitors and achieving first place. Throughout the race, verbal cues developed within the scenario were provided to the athlete via the VR headset, without any external stimuli. At the conclusion of the 30-second interval, the athlete was instructed to rest in a seated position (Fig. 5).

Measurements

A comprehensive set of demographic details pertaining to the athletes was collected, encompassing their age, height, weight, and the total duration of their sports experience. Subsequent to the administration of the tests, the System Usability Scale (SUS) was administered, and athletes were invited to rate their satisfaction with the two different test methods on a scale of 1 to 10, where 10 represented the highest satisfaction and 1 represented the lowest.

The bike system used for the WAnT automatically measured power generation in watts (W) or W/kg for each 5-second interval of the test. From these measurements, peak power, minimum power, average power, and fatigue index data were recorded for subsequent analysis. The fatigue index was calculated by dividing the difference between the highest and lowest power values obtained during any 5-second interval by the highest power value obtained during the test.

The System Usability Scale (SUS) is a 10-item questionnaire designed to rapidly evaluate the usability of websites, software, hardware, mobile devices, and other technological applications. Utilising a 5-point Likert scale, the SUS is a survey designed to evaluate the usability of technological applications and has been validated in Turkish. A SUS score greater than 68 indicates that the system's usability is above average [15].

Statistical analysis

The data collected for this study were analysed using SPSS (Statistical Package for Social Sciences) 23.0 (Armonk, NY, USA) and Jamovi software. The normality of the data was checked using the Shapiro-Wilk Test. The demographic data were expressed as the mean, min-max. For the purpose of intra-group comparisons, the parametric data were analysed using the paired Student's t-test. The Pearson correlation coefficient was used to examine the relationships between variables, assuming they were normally distributed. The strength of the correlations was described as: very weak (<0.10), weak (0.10–0.29), moderate (0.30–0.49), strong (0.50–0.69), very strong (0.70–0.89), almost perfect (0.90–0.99), and perfect (1.00) [16],. Cohen's d was used to estimate effect sizes by expressing the difference between two means in standardized units. According to common interpretation guidelines, $d \leq 0.2$-trivial, $0.2 < d \leq 0.6$-small, $0.6 < d \leq 1.2$-moderate, $1.2 < d \leq 2.0$-large, $2.0 < d \leq 4.0$-very large and $d > 4.0$-extremely large [17]. The results were evaluated at a 95% confidence interval, and the significance level was set at 0.05.

Table 1 Demographic characteristics of the participants

Variable	*n*	Mean ± SD	Min-Max
Age (years)	30	19.72 ± 1.13	18–22
Height (cm)	30	179.56 ± 0.545	170–188
Weight (kg)	30	75.22 ± 9.63	63–91
Sports experience (years)	30	9.6 ± 2.79	4–15
System Usability Scale	30	77.9 ± 14.6	40–95

Table 2 Analysis of measurement data

Variable	WAnT (Mean ± SD)	VR-WAnT (Mean ± SD)	*p*	ES
Maximum power	8.74 ± 1.063	8.96 ± 0.927	0.200	-0.239
Minimum power	5.37 ± 0.950	5.14 ± 1.040	0.227	0.183
Average power	7.07 ± 0.890	7.20 ± 0.728	0.343	-0.176
Fatigue index	3.37 ± 0.997	3.82 ± 1.113	0.091	-0.319
Satisfaction levels	7.53 ± 1.548	8.60 ± 1.773	**0.026***	-0.426

Student' t-test, *$p < 0.05$, ES: effect size

Table 3 Correlation between measurement data

Variable	WAnT (Mean ± SD)	VR-WAnT Mean ± SD)	*r*	*p*
Maximum power	8.74 ± 1.063	8.96 ± 0.927	**0.567****	**0.001**
Minimum power	5.37 ± 0.950	5.14 ± 1.040	0.228	0.226
Average power	7.07 ± 0.890	7.20 ± 0.728	**0.602*****	**< 0.001**
Fatigue index	3.37 ± 0.997	3.82 ± 1.113	0.101	0.596

Results

The study was thus completed with a total of 30 athletes. The demographic information of the participants is presented in Table 1.

The WAnT results obtained using different methods at different times are presented in Table 2. No statistically significant differences were identified between the athletes' maximum power, minimum power, average power, and fatigue index values ($p > 0.05$). The satisfaction level assessment indicated that the VR-WAnT results were statistically significant in comparison to the classic test results ($p = 0.026$).

Pearson correlation analysis was conducted to examine the relationship between the measurement values obtained from the WAnT performed with and without VR. The analysis revealed a strong and statistically significant positive correlation between maximum power values ($r = 0.567$, $p = 0.001$) and average power values ($r = 0.602$, $p < 0.001$) across the two test conditions. No significant correlations were found for minimum power or fatigue index (Table 3).

Discussion

This study aimed to explore the applicability of a VR based protocol as an alternative to the traditional administration of the WAnT, with a particular focus on user experience and performance-related aspects. While the VR condition appeared to offer certain advantages in terms of participant engagement and satisfaction, differences in anaerobic performance outcomes between the two methods were less pronounced. These preliminary observations suggest that VR-based testing environments may have potential benefits beyond purely physiological metrics, particularly in enhancing motivation and perceived enjoyment during anaerobic assessments tests.

VR applications offer users both ecological validity and experimental control, enhancing the realism of the environment [18]. Unlike traditional WAnT protocols, which rely solely on auditory stimuli, the VR-based scenario in this study incorporated simultaneous visual and auditory cues, including a competitive race environment with other cyclists, aimed at increasing participant motivation. Although performance improvements were observed in the VR-WAnT condition, these differences did not reach statistical significance. External verbal encouragement is widely used to enhance maximal performance in WAnT and is considered a key motivational factor. Findings on its effectiveness are mixed; some studies report no impact on anaerobic performance, whereas others demonstrate positive outcomes. Nonetheless, virtual reality remains a widely used tool for enhancing motivational context. This includes elements such as audience presence, individual or group competition, and performance-based consequences [14, 19]. Notably, concurrent verbal encouragement has been shown to positively influence WAnT performance in non-athlete male participants [20].

A review of the extant literature reveals that serious games (VR) have the potential to be applied in the context of analysing and determining sports performance [21]. Nevertheless, the efficacy of VR applications is commonly associated with their capacity to offer participants a high level of immersion. In a survey conducted to evaluate the immersive and engaging nature of a VR environment, it was found that experiences in virtual and real environments were comparable [18]. In the context of objective performance assessment in sports, it is imperative to ascertain that players exhibit equivalent behaviors in virtual and real environments, and that their perceptions and actions are consistent, a phenomenon referred to as behavioral realism. Bideau et al. [22] evaluated this behavioral realism by comparing the physical performance of a handball goalkeeper facing a real shooter versus a virtual avatar. The study revealed no statistically significant variation in reaction times, and there was a strong correlation between the movement of the arms and legs in both conditions. Pastel et al. [23] showed that reaction time, jump height, and multi-movement coordination tests administered in a VR environment were highly correlated with traditional tests and had strong reliability. Similarly, Sylcott et al. [24] demonstrated that the intrinsic motion sensors of VR headsets were significantly consistent with force platforms in postural sway measurements. Pratviel et al. [25] reported that both reaction time and head movement strategies could be measured with high test-retest reliability with the VR-based Dynavision test. In terms of upper extremity endurance, Maden et al. [26] emphasized that the VR version of the classic 6-Minute Pegboard and Ring Test produced similar physiological responses and was a valid assessment tool. In terms of evaluating tactical performance, Buga et al. [27] stated that VR-based aiming and decision-making tests showed significant relationships with age, physical activity level, and tactical training, and gave results similar to live shooting. Although no significant differences were found in maximum, minimum, or average power values, correlation analyses revealed significant positive relationships for maximum power and average power in our study. The calculated ES for maximum power indicates that the VR-WAnT protocol provides only a small advantage compared to the classical protocol. For minimum power and mean power, the effect sizes are quite low, and the practical significance of these differences is limited. These results suggest that the VR environment does not have a notable effect on short-term anaerobic power production, although it may create a limited difference. These results indicate that traditional and VR-based tests produce comparable motor outputs, and that the use of virtual reality does not compromise the reliability of performance data. Therefore, it can be suggested that VR-WAnT may be a viable alternative or an option among complementary digital solutions compared to traditional test protocols in the evaluation and rehabilitation processes.

Vignais et al. [28] demonstrated that a handball goalkeeper performed better in a 3D virtual reality environment compared to 2D video, attributing this improvement to the presence of stereoscopic information. Similarly, the player's ability to adapt their viewpoint in 3D space has been identified as crucial for accurately perceiving visual cues [18]. Supporting this, research indicates that sports performance assessments are enhanced when VR systems incorporate stereo vision and head movement tracking [29]. In the present study, the traditional WAnT was conducted in a 3D VR environment, and the results suggest that integrating stereoscopic vision into such protocols may contribute to improved anaerobic performance.

Encouragement may prove pivotal in achieving their maximum potential during exercise tests for less-trained individuals, as these individuals exhibit diminished intrinsic motivation to exert maximum effort when compared to their more trained counterparts [30]. In the present study, the similar outcomes observed in both the classic and VR-WAnT experiments may be attributed to the athletes' high intrinsic motivation at the commencement of the trials. The findings of this study suggest that the implementation of VR-WAnT in the training of amateur athletes could yield effective results when compared with the conventional WAnT method.

Despite the acknowledged importance of external encouragement in enhancing exercise performance, as noted in several guidelines [31, 32], only one guideline outlines specific timing and delivery methods, which remains empirically unverified and is not exclusive to maximal exercise tests [33]. This gap likely stems from the limited methodological detail in existing studies on verbal encouragement, particularly regarding its frequency, intensity, and volume. The lack of standardisation impedes the ability to determine whether variations in these parameters explain differences in observed effects. For instance, in healthy adolescents, encouragement delivered at 20–60 s intervals significantly improved maximal effort compared to no or minimal encouragement at 180 s intervals [34]. Comparable findings were reported in studies on vertical jump and resistance training performance, where variations in encouragement strategies led to differing outcomes [35–37]. Moreover, the intensity of encouragement influences force production and may affect exhaustion thresholds. Accordingly, developing a standardised protocol could inform clinical guidelines to help individuals reach maximal performance [38]. An advantage of the VR-WAnT used in this study is its ability to provide athletes with a realistic and consistent testing environment compared to the traditional WAnT, thereby enhancing standardization in performance analysis [39–41]. Consequently, training efficiency and competitive performance may be improved.

The finding of comparable outcomes in both the classic WAnT and the VR-WAnT models lends further support to the utilisation of virtual reality in WAnT. A key strength of the study lies in the potential for a standardized encouragement protocol in VR-WAnT, which could enhance consistency across individuals and within individuals when compared to the classic WAnT. It is hypothesised that this approach will enhance the reliability and validity of physiological results obtained through exercise tests. Furthermore, it can be integrated into clinical guidelines and future research. Furthermore, the integration of VR with software or artificial intelligence holds considerable potential for the future development of personalized encouragement protocols, tailored to individual physiological responses and test results. The findings of this study may also have relevance for VR-supported exercise tests in other areas.

This study has several limitations. The participants were male football players aged between 18 and 25, which restricts the generalizability of the findings in terms of age, gender, and sport type. The study was focused on assessing the acute performance of the WAnT, and did not evaluate the learning effects of repeated VR-WAnT trials, nor the long-term effects on performance maintenance or fatigue modulation. The lack of randomization in the order of test administration may have introduced potential learning or familiarity effects. Although participants were selected from football players who had previously completed the WAnT outside the scope of this study in order to minimize such biases, the possibility of residual learning effects cannot be completely ruled out. Additionally, blinding was not applied as participants were aware that they were testing a new VR system. The inherent potential of the VR application developed within the scope of the study to enhance motivation may have introduced bias in the assessments of satisfaction and fatigue. Future studies should be encouraged to randomizing the test order and include more diverse populations (e.g., female athletes, different sports disciplines, older age groups) to improve generalizability of findings.

Conclusions

Consequently, no statistically significant differences were observed in power parameters and fatigue index between the VR-based and traditional Wingate test. However, participant satisfaction was significantly higher in the VR group compared to the traditional group. These findings suggest that the VR-based method may offer additional advantages in terms of user experience and motivation. Considering the potential benefits of the VR-WAnT, such as enhanced satisfaction and feedback standardization, it may be seen as a viable and promising alternative for anaerobic performance testing.

Acknowledgements

We are thankful to the The Scientific and Technological Research Council of Türkiye (TÜBİTAK) for providing financial support for this study.

Author contributions

Conceptualization, Y.Y., G.A.B., G.E.S., and P.K.S.; methodology, G.A.B., G.E.S., P.K.S., Y.Y., and D.T.; software, D.T.; validation, A.G.C., and G.Y.; formal analysis, Y.Y., and U.I.T.; data curation, G.E.S., and G.Y.; writing-original draft preparation, G.A.B., P.K.S., Y.Y., and U.I.T.; writing-review and editing, G.A.B., G.E.S., and D.T. All authors have read and agreed to the published version of the manuscript.

Funding

This study was funded by The Scientific and Technological Research Council of Türkiye (TÜBİTAK 1002-A Short term Support Module-223S022, 15.10.2023).

Data availability

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. The datasets generated and/or analyzed during the current study are not publicly available due to data security before publication but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Istanbul Medipol University Non-Interventional Clinical Studies Ethics Committee (E-10840098-772.02-7702; 23.12.2022). This study followed the ethical principles of the Helsinki Declaration for human research. Consent to participate informed consent was obtained from all the participants in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 31 January 2025 / Accepted: 10 June 2025
Published online: 02 July 2025

References

1. Krishnan A, Sharma D, Bhatt M, Dixit A, Pradeep P. Comparison between standing broad jump test and wingate test for assessing lower limb anaerobic power in elite sportsmen. Med J Armed Forces India. 2017;73(2). https://doi.org/10.1016/j.mjafi.2016.11.003.,140– 45.
2. Bertuzzi R, Kiss M, Damasceno M, Oliveira R, Lima-Silva AE. Association between anaerobic components of the maximal accumulated oxygen deficit and 30-second wingate test. Braz J Med Biol Res. 2015;48:261–66. https://doi.org/10.1590/1414-431X20144043.
3. Inbar O, Bar-Or O, Skinner JS. The wingate anaerobic test. Champaign, Ill: Human Kinetics; 1996.
4. Argus CK, Gill ND, Keogh JW, Hopkins WG. Acute effects of verbal feedback on upper-body performance in elite athletes. J Strength Cond Res. 2011;25(12):3282–87. https://doi.org/10.1519/JSC.0b013e3182133b8c.
5. Chanda ML, Levitin DJ. The neurochemistry of music. Trends Cogn Sci. 2013;17:179–93. https://doi.org/10.1016/j.tics.2013.02.007.
6. Castañeda-Babarro A, Marqués-Jiménez D, Calleja-González J, Viribay A, León-Guereño P, Mielgo-Ayuso J. Effect of listening to music on wingate anaerobic test performance. A systematic review and Meta-Analysis. Int J Environ Res Public Health. 2020;17(12):4564. https://doi.org/10.3390/ijerph17124564.
7. Mirelman A, Maidan I, Deutsch JE. Virtual reality and motor imagery: promising tools for assessment and therapy in Parkinson's disease. J Mov Disord. 2013;28(11). https://doi.org/10.1002/mds.25670,1597– 608.
8. Gonzalez-Franco M, Lanier J. Model of illusions and virtual reality. Front Psychol. 2017. https://doi.org/10.3389/fpsyg.2017.01125. 8,1125.
9. Bevilacqua R, Maranesi E, Riccardi GR, et al. Non-immersive virtual reality for rehabilitation of the older people: a systematic review into efficacy and effectiveness. J Clin Med. 2019;8(11):1882. https://doi.org/10.3390/jcm8111882.
10. Nambi G, Abdelbasset WK, Alrawaili SM, Alsubaie SF, Abodonya AM, Saleh AK. 2021. Virtual reality or isokinetic training; its effect on pain, kinesiophobia and serum stress hormones in chronic low back pain: A randomized controlled trial. Technol Health Care. 2021;29(1),155– 66. https://doi.org/10.3233/THC-202301
11. Smith CM, Read JE, Bennie C, Hale LA, Milosavljevic S. Can non-immersive virtual reality improve physical outcomes of rehabilitation? Phys Therapy Reviews. 2012;17(1):1–15. https://doi.org/10.1179/1743288X11Y.0000000047.
12. Yang Z, Rafiei MH, Hall A, et al. A novel methodology for extracting and evaluating therapeutic movements in game-based motion capture rehabilitation systems. J Med Syst. 2018;42(12):1–14. https://doi.org/10.1007/s10916-018-1113-4.
13. Cameirão MS, Badia SB, Oller ED, Verschure PF. Neurorehabilitation using the virtual reality based rehabilitation gaming system: methodology, design, psychometrics, usability and validation. J Neuroeng Rehabil. 2010;7:48. https://doi.org/10.1186/1743-0003-7-48.
14. Bar-Or O. The wingate anaerobic test. An update on methodology, reliability and validity. Sports Med. 1987 Nov-Dec;4(6):381–94. https://doi.org/10.2165/00007256-198704060-00001.
15. Demi̇rkol D, Şeneler Ç. A Turkish translation of the system usability scale: the SUS-TR. Uşak Üniversitesi Sosyal Bilimler Dergisi. 2018;11(3):237–53. https://doi.org/10.29217/uujss.495.
16. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J. 2012;24(3):69–71.
17. Hopkins WG. A Scale of Magnitudes for Effect Statistics: A New View of Statistics. 2002 http://www.sportsci.org/resource/stats/effectmag.html
18. Faure C, Limballe A, Bideau B, Kulpa R. Virtual reality to assess and train team ball sports performance: A scoping review. J Sports Sci. 2020;38(2):192–205. https://doi.org/10.1080/02640414.2019.1689807.
19. Bullinger DL, Hearon CM, Gaines SA, Daniel ML. Concurrent verbal encouragement and wingate anaerobic cycle test performance in females: athletes vs. Non-Athletes. Int J Exerc Sci. 2012;5(3). https://doi.org/10.70252/JGRR1663.,239– 44.
20. Karaba-Jakovljevic D, Popadic-Gacesa J, Grujic N, Barak O, Drapsin M. Motivation and motoric tests in sports. Medicinski Pregled. 2007;60(5–6):231–6. https://doi.org/10.2298/mpns0706231k.
21. Bideau B, Kulpa R, Vignais N, Brault S, Multon F, Craig C. Using virtual reality to analyze sports performance. IEEE Comput Graph Appl. 2010;30(2):14–21. https://doi.org/10.1109/MCG.2009.134.
22. Bideau B, Kulpa R, Ménardais S, et al. Real handball goalkeeper vs. virtual handball thrower. Presence. 2003;12(4):411–21. https://doi.org/10.1162/105474603322391631.
23. Pastel S, Klenk F, Bürger D, Heilmann F, Witte K. Reliability and validity of a self-developed virtual reality-based test battery for assessing motor skills in sports performance. Sci Rep. 2025;15(1):6256. https://doi.org/10.1038/s41598-025-89385-3.
24. Sylcott B, Lin CC, Williams K, Hinderaker M. Investigating the use of virtual reality headsets for postural control assessment: instrument validation study. JMIR Rehabil Assist Technol. 2021;8(4):e24950. https://doi.org/10.2196/24950.
25. Pratviel Y, Deschodt-Arsac V, Larrue F, Arsac LM. Reliability of the dynavision task in virtual reality to explore visuomotor phenotypes. Sci Rep. 2021;11(1):587. https://doi.org/10.1038/s41598-020-79885-9.
26. Maden Ç, Gözaçan Karabulut D, Bağcı B. Validity and reliability of an immersive virtual reality adaptation of the 6-minute pegboard and ring test. Hand Surg Rehabil. 2025;44(1):101981. https://doi.org/10.1016/j.hansur.2024.101981.
27. Buga A, El-Shazly X, Crabtree CD, Stoner JT, Arce L, Decker DD, Robinson BT, Kackley ML, Sapper TN, Anders JPV, Kraemer WJ, Volek JS. Age and weekly physical activity are correlated with ballistic VR decision making and reaction time shooting performance at rest. Sci Rep. 2025;15(1):14412. https://doi.org/10.1038/s41598-025-98144-3.
28. Vignais N, Kulpa R, Brault S, Presse D, Bideau B. Which technology to investigate visual perception in sport: video vs. virtual reality. Hum Mov Sci. 2015;39:12–26. https://doi.org/10.1016/j.humov.2014.10.006.
29. Ragan ED, Kopper R, Schuchardt P, Bowman DA. Studying the effects of stereo, head tracking, and field of regard on a small-scale Spatial judgment task. IEEE Trans Vis Comput Graph. 2013;19(5), 886– 96. https://doi.org/10.1109/TVCG.2012.163
30. Stanger N, Kavussanu M, Ring C. The effects of verbal encouragement on performance and perceived exertion during a maximal graded exercise test. Sports. 2019;7(1):12. https://doi.org/10.1080/026404102753576125.
31. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 9th ed. Philadelphia: Lippincott Williams and Wilkins; 2014.
32. Andrew P, Paul B, Joao C, et al. ARTP statement on cardiopulmonary exercise testing. BMJ Open Respir Res. 2021;8(1):e001121. https://doi.org/10.1136/bmjresp-2021-001121.
33. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the Six-Minute walk test. Am J Respir Crit Care Med. 2002;166, 111-7https://doi.org/10.1164/ajrccm.166.1.at1102.
34. Andreacci Joseph L, Lemura Linda M, Cohen Steven L, Urbansky Ethan A, Chelland Sara A, Duvillard Serge P. The effects of frequency of encouragement on performance during maximal exercise testing. J Sports Sci. 2002;20(4), 345– 52. https://doi.org/10.1080/026404102753576125.
35. Martin K, Benedikt L, Marius G, Wolfgang T. Enhanced jump performance when providing augmented feedback compared to an external or internal focus of attention. J Sports Sci. 2015;33(10):1067–75. https://doi.org/10.1080/02640414.2014.984241.
36. Rendos NK, Harriell K, Qazi S, Regis RC, Alipio TC, Signorile JF. Variations in verbal encouragement modify isokinetic performance. J Strength Cond Res. 2019;33(3). 708– 16https://doi.org/10.1519/JSC.0000000000002998.
37. Jonathon W, Kyle W, Kevin T, et al. Show me, tell me, encourage me: the effect of different forms of feedback on resistance training performance. J Strength Cond Res. 2020;34(11):3157–63. https://doi.org/10.1519/JSC.0000000000002887.
38. Van Hooren B, Van Der Lee P, Plasqui G, Bongers BC. The effect of a standardized verbal encouragement protocol on peak oxygen uptake during incremental treadmill testing in healthy individuals: A randomized cross-over trial. Eur J Sport Sci. 2024;24(1):16–25. https://doi.org/10.1002/ejsc.12044.
39. Cossich VRA, Carlgren D, Holash RJ, Katz L. Technological breakthroughs in sport: current practice and future potential of artificial intelligence, virtual reality, augmented reality, and modern data visualization in performance analysis. Appl Sci. 2023;13(23):12965. https://doi.org/10.3390/app132312965.

40. Akbaş A, Marszałek W, Kamieniarz A, Polechoński J, Słomka KJ, Juras G. Application of virtual reality in competitive Athletes - A review. J Hum Kinet. 2019;69:5–16. https://doi.org/10.2478/hukin-2019-0023.
41. Wan H. Sensor action recognition, tracking, and optimization analysis in training process based on virtual reality technology. Wirel Commun Mob Comput. 2022;1–7. https://doi.org/10.1155/2022/1564390.