Spor Bilimleri Araştırmaları Dergisi
Journal of Sport Sciences Research
Vol: 11, Issue: 2, 2026
E-ISSN: 2548-0723
URL: http://www.dergipark.org.tr/jssr

Acute Influence of Respiratory Muscle Activation on Movement Velocity in Elite Weightlifters

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Research Article **DOI: 10.25307/jssr.1837259**
Received: 06.12.2025 Accepted: 16.03.2026 Online Published: 30.06.2026

Abstract

Inspiratory muscle warm-up (IMW) has been proposed as an acute priming strategy that may enhance high-intensity exercise performance by improving ventilatory muscle function and reducing reflex sympathetic vasoconstriction associated with respiratory muscle fatigue. However, its acute influence on velocity-based strength assessments in weightlifting is unclear. This study investigated the acute effect of IMW on barbell-velocity variables obtained in a velocity-based maximal strength test in elite weightlifters. Seven male elite weightlifters completed three randomized, counterbalanced conditions in a controlled crossover design: IMW, SHAM (same procedure at 0% resistance), and control (no inspiratory warm-up). After a standardized sport- and movement-specific warm-up, athletes performed six maximal-effort front-squat repetitions at 80% of one-repetition maximum. Mean propulsive velocity (MPV), average velocity (AV), and peak velocity (PV) were recorded using a linear position transducer (ENODE Pro). A condition effect was observed for MPV, with IMW producing lower MPV than sham and control. No significant condition effects were detected for PV or AV. In elite weightlifters performing front squats at 80% 1RM, IMW did not acutely increase barbell velocity and was associated with a small-to-moderate reduction in MPV. Further studies should clarify whether this reflects altered bracing strategies, pacing behavior, or a dose-dependent response to inspiratory priming.

Keywords: Inspiratory muscle warm-up, Velocity-based training, Front squat, Maximal strength, Weightlifting

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Spor Bil Araş Derg/J Sport Sci Res, 11(2):197-209.

INTRODUCTION

High-performance sport warm-up strategies have shifted from broad, one-size-fits-all routines to more specific protocols intended to prime particular physiological systems. Beyond elevating muscle temperature and improving joint mobility, modern warm-up methods also seek to enhance neuromuscular preparedness and acute performance by acting through several mechanisms (Bishop, 2003).

Respiratory muscles can influence whole-body performance through both mechanical and reflex pathways. During strenuous exercise, high respiratory work may compete with locomotor muscles for blood flow, potentially compromising limb perfusion (Dempsey et al., 2006; Harms et al., 2000). In parallel, respiratory muscle fatigue can activate a metaboreflex that elevates sympathetic vasoconstrictor activity and reduces oxygen delivery to active limb muscles (Witt et al., 2007).

Inspiratory muscle warm-up (IMW) has therefore been investigated as an acute priming strategy performed immediately before exercise. IMW can acutely improve indices of inspiratory muscle function and reduce perceived breathlessness, with many studies focusing on endurance performance (Shei, 2018; Turner et al., 2011; Volianitis et al., 2001). Evidence in strength- and power-oriented tasks is more limited, but improvements in sprint/agility and neuromuscular responses have been reported in some athletic populations (Sukatan et al., 2022; Yılmaz et al., 2025). These effects may relate to altered respiratory–locomotor coupling, attenuation of fatigue-related reflex inhibition, and changes in trunk stabilization demands during high-force movements. Recent syntheses indicate that the acute ergogenic potential of inspiratory muscle warm-up is task- and protocol-dependent. Across studies, IMW has been associated with transient improvements in inspiratory muscle function and altered perceptions of breathing discomfort, which may delay the onset of respiratory muscle fatigue–related inhibitory feedback during subsequent exercise (Cheng et al., 2013; Koizumi & Ohya, 2023). However, the literature also reports null findings, suggesting that performance benefits are not guaranteed and may be constrained by factors such as load carriage, exercise mode, or the interaction between the IMW stimulus and the subsequent task demands (Faghy & Brown, 2017). A recent systematic review further emphasized that methodological heterogeneity (e.g., intensity prescription, sham implementation, and timing relative to the main task) likely contributes to mixed outcomes, underscoring the need for sport-specific testing and standardized reporting of IMW protocols (Cirino et al., 2023).

Overall, evidence suggests that the acute effects of inspiratory muscle warm-up are highly context-dependent and may vary with protocol intensity, timing, and the specific demands of the subsequent task. While several studies report improvements in respiratory-related sensations and performance in endurance-oriented settings, findings remain inconsistent in strength- and power-dominant tasks, highlighting the need for sport-specific testing with appropriate sham conditions and sensitive outcome measures (Koizumi & Ohya, 2023; Shei, 2018). In addition, national studies have explored respiratory muscle warm-up applications in different sport contexts, supporting the practical relevance of protocol standardization (Sukatan et al., 2022).

Weightlifting performance depends on rapid force production and effective force transmission during complex multi-joint lifts. Velocity-based training (VBT) provides sensitive metrics of neuromuscular output via barbell-velocity variables and is frequently used to prescribe load and monitor fatigue (González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014; Weakley et al., 2021). Despite the popularity of both IMW and VBT, their acute interaction during heavy resistance exercise has been insufficiently studied, particularly in elite weightlifters. Recent applied evidence indicates that targeted respiratory muscle interventions can enhance respiratory muscle function and may translate into improvements in broader performance outcomes in trained athletes (Bahcecioğlu & Yapıcıoğlu, 2024). In parallel, work using the load–velocity relationship supports the practical value of velocity profiling for estimating maximal strength and for detecting subtle changes in neuromuscular output (Aksakallı & Gelen, 2023). Complementary findings linking lower-body force production measures with anaerobic power indices further support combining sensitive strength/power assessments with acute intervention models; however, whether a brief inspiratory muscle warm-up produces detectable changes in barbell-velocity during heavy, strength-dominant lifts in elite weightlifters remains unclear (Vural et al., 2023). Therefore, the primary aim of this study was to determine whether a short-duration IMW protocol performed prior to a velocity-based maximal strength assessment modifies barbell-velocity parameters during the front squat in elite weightlifters. It was hypothesized that IMW would acutely enhance mean propulsive velocity compared with sham and control conditions.

METHOD

Research Model

The study was conducted using a randomized crossover experimental design. A randomized crossover design is a repeated measures design in which each participant is randomly assigned to a sequence of treatments, meaning each subject receives all interventions in a specific order (Thomas et al., 2015).

Research groups

Seven male elite weightlifters volunteered to participate. Sample size was informed by a priori power analysis (α = .05, power = .95) using an effect size (d = 0.87) reported for bar-velocity outcomes in lower-limb resistance exercise (Conceição et al., 2016). Recruiting elite-level weightlifters was also practically constrained. All participants were familiar with the front squat and reported no acute injury at the time of testing.

Table 1. Demographic characteristics of participants

		Min.	Max.	X±SD
Participants (N:7)	Age (year)	19.00	22.00	20.71 ± 0.95
	Body Height (cm)	160.00	185.00	171.86 ± 10.24
	Body Mass (kg)	57.00	96.00	75.29 ± 14.71
	80% of Maximum Force (kg)	100.00	130.00	115.71 ± 12.72

Min: minimum, Max: maximum, X: Mean, SD: Standard Deviation

In Table 1, descriptive statistics of the basic anthropometric characteristics of the athletes participating in the study, such as age, height, weight, and 80% of their maximum strength (80% 1RM), are presented. The mean age of the athletes was 20.71 ± 0.95 years, and the mean body height was 171.86 ± 10.24 cm. The participants' body mass was 75.29 ± 14.71 kg. Regarding the strength measurements, the values corresponding to 80% of the maximum strength of the participants were determined as 115.71 ± 12.72 kg.

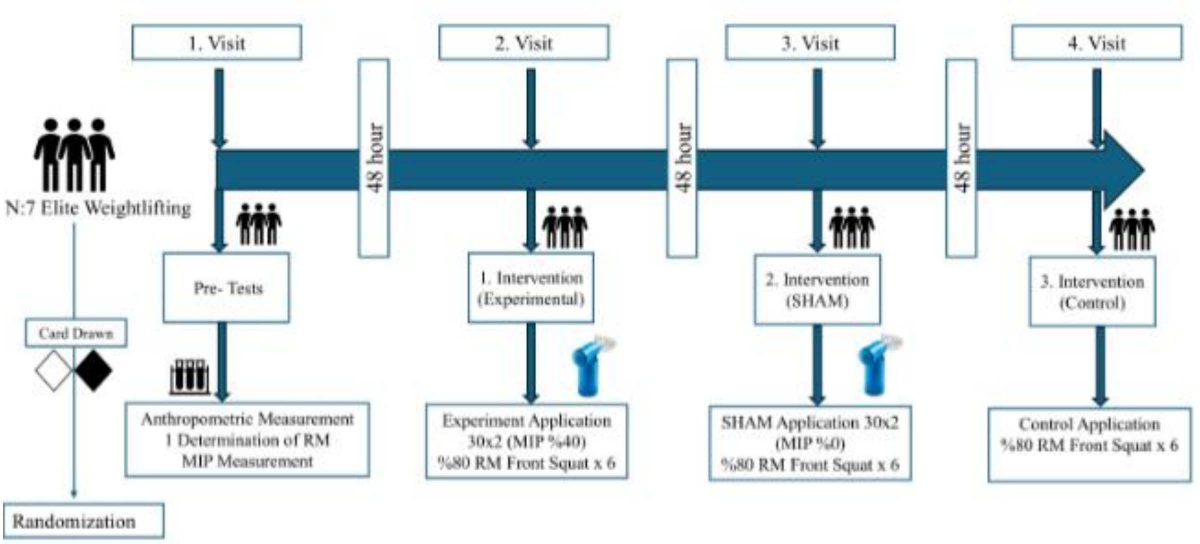

Figure 1. Study flow diagram

Interventions

Each athlete completed three experimental conditions (IMW, Sham, Control) on separate days, with ≥48 h between sessions. Each experimental visit began with a standardized sport- and movement-specific warm-up. In the IMW condition, athletes performed 2 sets of 30 breaths on an inspiratory muscle training device (PowerBreathe, UK) at a resistance equal to 40% of their measured MIP, with 1 min rest between sets. The 40% MIP intensity was selected based on previous inspiratory muscle warm-up studies indicating that moderate intensities (30–40% MIP) enhance neural activation without inducing respiratory fatigue (Tong & Fu, 2006). In the sham condition, athletes performed the same breathing pattern with the device set to 0% resistance. In the control condition, no inspiratory protocol was performed.

Data Collection Tools

Assessment of MIP: Maximal inspiratory pressure (MIP) was measured using an electronic respiratory pressure meter (Pocket Spiro MPM-100, Medical Electronic Construction R&D, Brussels, Belgium) following established guideline principles (Polkey et al., 1995). Participants performed maximal expiration followed by maximal inspiration against an occluded airway for 1–3 s. Trials were repeated until the two best efforts differed by <5 cmH_2O; the highest value was recorded

Determination of 1RM: Front-squat one-repetition maximum (1RM) was determined during the first visit using standardized procedures (Baechle & Earle, 2008). Athletes performed 5–10 min of low-intensity aerobic activity followed by dynamic mobility. Warm-up sets included 5–10 repetitions at ~40–60% estimated 1RM and 2–5 repetitions at ~60–80% estimated 1RM. Load was then increased progressively until the athlete completed a single repetition with correct technique and full range of motion. Rest intervals of 3–5 min were provided between maximal attempts. The highest successfully lifted load was recorded as 1RM (Willardson & Burkett, 2008). The 80% 1RM load was selected because this intensity is commonly used for maximal strength assessment and provides stable and reliable velocity outputs during velocity-based testing in trained populations (González-Badillo & Sánchez-Medina, 2010). Moreover, intensities ≥80% 1RM are considered strength-dominant loads, making them suitable for detecting subtle changes in neuromuscular performance.

Velocity-based force measurement: After completing the assigned condition, athletes performed six front-squat repetitions at 80% of 1RM with maximal intent and were instructed to complete the concentric phase “as fast as possible” while maintaining correct technique. Barbell-velocity data were collected via a linear position transducer (ENODE Pro, Enode Ltd., Finland) secured to the barbell. The system sampled bar displacement at 1000 Hz and automatically computed mean propulsive velocity (MPV), average velocity (AV), and peak velocity (PV) for each repetition. For statistical analyses, the session value for each metric was defined as the mean across the six repetitions (Mann et al., 2015).

Outcome variables: The primary outcome measure was MPV ($m \cdot s^{-1}$), defined as the mean concentric velocity achieved during the propulsive phase. The secondary outcome measures were AV ($m \cdot s^{-1}$) and PV ($m \cdot s^{-1}$)

Figure 2. Placement of the Enode Pro Device on the bar

Ethics Approval

Ethical approval was obtained from the Gaziantep University Sports and Health Ethics Committee (Protocol No: 569375; 16 June 2025). All participants provided informed consent. Procedures conformed to the Declaration of Helsinki. Following the ethical approval, data collection was conducted between June 2025 and August 2025.

Analysis of Data

Data were analyzed using SPSS (version 25). Descriptive statistics are presented as mean ± SD. Normality was assessed with Shapiro–Wilk tests. Condition effects (IMW, sham, control) were examined with repeated-measures ANOVA. When appropriate, Bonferroni-adjusted pairwise comparisons were used. Statistical significance was set at $p < .05$ and partial eta squared (ηp^2) was reported as an effect-size index.

RESULTS

The results of this study are presented through statistical analyses of the data obtained across the three experimental conditions. Descriptive statistics are reported as mean ± SD, and inferential analyses were performed to determine whether the inspiratory muscle warm-up produced acute changes in barbell-velocity outcomes during the front squat.

Table 2. Comparison of speed parameters between treatment groups and analysis of variance results

		Mean ± SD	**f**	**p**	**ηp2**
MPV ($m \cdot s^{-1}$)	Exp.	$0.60^{a} \pm 0.04$	3.557	**0.05**	0.283
	SHAM	0.67 ± 0.07			
	Control	0.68 ± 0.08			
PV ($m \cdot s^{-1}$)	Exp.	0.76 ± 0.11	2.629	0.10	0.226
	SHAM	0.88 ± 0.12			
	Control	0.88 ± 0.10			
AV ($m \cdot s^{-1}$)	Exp.	0.54 ± 0.04	1.735	0.20	0.162
	SHAM	0.58 ± 0.07			
	Control	0.59 ± 0.05			

p<0.05; a: Significant difference in favor of the experimental treatment; Exp: Experimental Group. **MPV**: Mean Propulsive Velocity; **PV**: Peak Velocity; **AV**: Average Velocity

In Table 2, the effect of different applications on the velocity-based force measurement results is analyzed (Figure 3). In terms of movement speed, the experimental group had an average value of 0.60 ± 0.04 m/s, while the sham and control groups had values of 0.67 ± 0.07 and 0.68 ± 0.08 m/s, respectively. The ANOVA result ($F = 3.557$, $p = 0.050$) indicates a significant difference between the groups. This significant difference favored the experimental group, indicating that the respiratory muscle warm-up effectively improved movement speed. ($\eta p^2 = 0.283$). In peak velocity values, the average of the experimental group was 0.76 ± 0.11 m/s, whereas these values were 0.88 ± 0.12 and 0.88 ± 0.10 m/s in the sham and control groups, respectively. The F-test result ($F = 2.629$, $p = 0.10$) was not within the significance limit, indicating that the difference between the groups was not statistically significant. However, the effect size ($\eta p^2 = 0.226$) indicates a moderate effect. In the mean velocity parameter, the experimental group had a value of 0.54 ± 0.04 m/s, the sham group 0.58 ± 0.07 m/s, and the control group 0.59 ± 0.05 m/s. ANOVA results ($F = 1.735$, $p = 0.20$) showed that there was no significant difference between the groups ($\eta p^2 = 0.162$).

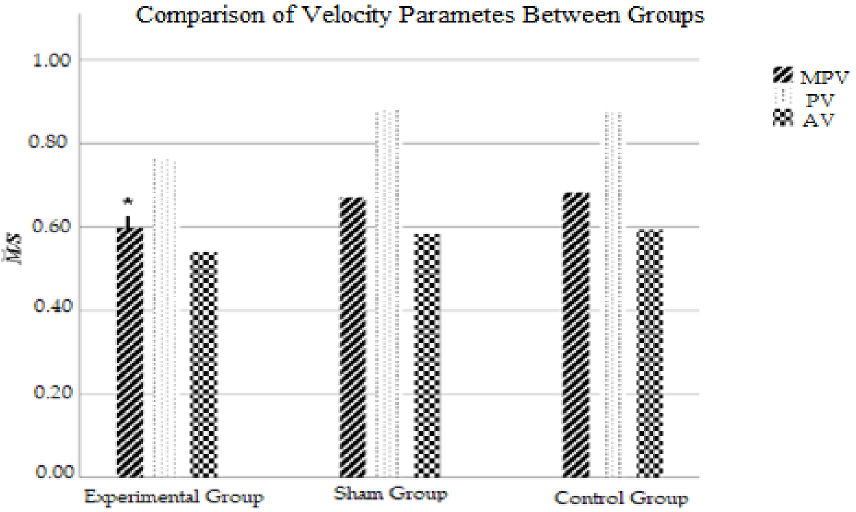

Figure 3. Comparison of Velocity Parameters between Groups

DISCUSSION and CONCLUSION

The present study examined whether an inspiratory muscle warm-up (IMW) could acutely enhance performance in velocity-based strength assessment in elite weightlifters. The primary finding was a significant reduction in concentric movement time during the front squat under the IMW condition compared with control trials. Given that movement velocity is inversely proportional to movement time, this reduction suggests a potential increase in execution speed based on time-derived analysis. These findings suggest that respiratory muscle pre-activation may positively influence explosive strength performance in highly trained athletes. For this purpose, the study was conducted with seven elite weightlifters who are internationally competitive. When the study results, obtained through four visits in total, were examined, it was determined that the movements were performed with relatively faster execution times and improved timing characteristics in the experimental application that the athletes supported with respiratory muscle warm-up, in addition to movement-specific warm-up. Among the values monitored with the help of necessary sensors and devices used for speed-based force measurement, a significant difference was observed in favor of the experimental application in the front squat movement, which is a movement requiring high-performance specific to the weightlifting branch in terms of movement speed ($p < 0.05$). When examining other parameters based on speed, it was observed that although there is no significant difference between the treatments in average speed and peak speed values, the values are more positive in favor of the respiratory muscle application. It should be clarified that the observed decrease refers specifically to movement duration rather than barbell velocity; therefore, shorter execution time corresponds to enhanced movement speed under constant displacement conditions. This distinction is important, as time-derived measures and direct velocity metrics may respond differently to acute neuromuscular interventions, particularly in high-load strength exercises.

In weightlifting, the fast and coordinated execution of movements that require explosiveness is one of the most important factors in achieving success. It is believed that various psychological and physical factors, as well as several physiological mechanisms, contribute to overcoming the resistance encountered during competition. The most important of these is related to the efficiency of the respiratory system. This increase in movement speed may be attributed to the fact that warm-up exercises involving respiratory muscle pre-activation increase the excitability of the central nervous system. It has been demonstrated that warming the respiratory muscles increases blood flow and oxygenation in other muscle groups, primarily the primary respiratory muscles. It is suggested that this effect may support the maintenance of overall motor output by delaying ventilatory muscle fatigue (Romer & Polkey, 2008). Furthermore, inspiratory muscle warm-up performed prior to maximum effort can increase neuromuscular activation in both respiratory muscles and peripheral muscle groups (Romer et al., 2002). In this context, the increase in movement speed observed in our study suggests that the rise in respiratory muscle activation may have made the integration between central and peripheral neural processes more efficient during exercise.

Current findings suggest that pre-activation of inspiratory muscles may increase corticospinal excitability, which in turn may support higher motor unit recruitment in both respiratory and locomotor muscles (Shirakawa et al., 2015). This neuromodulatory effect may increase the responsiveness of the motor cortex while reducing inhibitory afferent feedback associated with respiratory muscle fatigue. This may contribute to more efficient execution of movement. Additionally, inspiratory muscle warming has been reported to increase blood flow and oxygenation to the diaphragm (Koizumi & Ohya, 2024). This may contribute to a later onset of ventilatory muscle fatigue and a more favourable distribution of blood flow to the active limb muscles. When all these data are considered together, it is thought that the higher movement speed observed in our study may be related to improved coordination at the central or peripheral level and reduced neural inhibition.

Koizumi and Ohya (2023) demonstrated that high-intensity inspiratory heating (80% MIP) significantly increased maximum inspiratory pressure (MIP) values and led to an increase in the electromyographic (EMG) activity of the accessory respiratory muscles. Researchers have suggested that these effects may be related to the earlier activation of the central nervous system, which may facilitate the more regular and coordinated activation of motor units. Similarly, Marostegan et al. (2022) reported that the IMW protocol applied to intermediate-level runners increased muscle oxygenation while also improving mechanical power output. When these findings are considered together, it is understood that the effect of respiratory muscle pre-activation is not limited to ventilatory function but may support performance in a broader context. Consistent with this interpretation, the relatively faster execution time observed in our study may be related to enhanced intramuscular coordination and increased motor unit synchronisation. This situation is particularly important in weightlifting and similar disciplines where rapid force generation and high force must be produced simultaneously and can directly impact performance.

Harms et al. (2000) emphasised that respiratory muscle fatigue may exert an inhibitory effect on the central nervous system, which may ultimately limit motor output. Beyond this neural modulation, subsequent studies have highlighted the importance of reflex pathways linking respiratory and locomotor functions. In particular, respiratory muscle fatigue can increase sympathetic vasoconstrictor activity by triggering metaboreflex. This response has the potential to reduce oxygen delivery to the limb muscles (Witt et al., 2007).

Furthermore, the changes observed in speed-based force outputs are largely related to the mechanical behaviour of the muscle–tendon complex. The increase in movement speed is dependent on the effective expression of explosive capacity, and this characteristic is closely linked to the synchronised activation of motor units (Cormie et al., 2011). From this perspective, it can be argued that respiratory muscle warm-up may support faster and stronger contractions of agonist muscles by increasing central nervous system drive at a general level (Tong & Fu, 2006).

Our findings also demonstrate that velocity-based training (VBT) metrics offer significant practical value. VBT not only contributes to the planning and optimisation of load but also facilitates the monitoring of fatigue and the tracking of exercise-specific adaptations (Weakley et al., 2021). VBT can provide more sensitive and explanatory feedback compared to traditional 1RM assessments, as it allows the load to be adjusted according to the athlete's individual strength characteristics and strength–velocity relationship (Jovanović & Flanagan, 2014). In this context, the differences observed in movement speed outputs across conditions in our study reflect not only physiological effects but also the sensitivity of the measurement approach used. As emphasised by Weakley et al. (2021), combining VBT load control with speed-based monitoring allows for a more detailed assessment of motor performance. Therefore, the measurement sensitivity provided by VBT in this study made it possible to distinguish the effects of respiratory muscle warm-up more clearly.

Conclusion

Inspiratory muscle warm-up influenced certain time-based movement parameters during velocity-based strength assessment in elite weightlifters. Although concentric movement time was significantly reduced in the IMW condition, mean propulsive velocity did not show a corresponding increase and tended to be lower compared with control conditions. These findings suggest that respiratory muscle pre-activation may alter movement execution characteristics without consistently enhancing velocity-based performance metrics. However, it should also be noted that mean propulsive velocity (MPV) did not demonstrate a parallel increase and tended to be lower under the IMW condition, indicating that the observed improvement may be more closely related to execution timing characteristics rather than a uniform enhancement of all velocity-based outputs. Therefore, while IMW may affect neuromuscular behaviour acutely, its ergogenic value in high-load strength tasks remains inconclusive in elite populations.

Practical Implications

- Respiratory muscle pre-activation may be integrated immediately before training or competition attempts when the goal is to maximize movement velocity and explosive performance.

- Practitioners working with elite weightlifters may consider respiratory muscle warm-up as a priming element within pre-lift routines, especially in sessions emphasizing high-velocity outputs.
- Velocity-based monitoring can be used to detect subtle acute changes following respiratory muscle interventions and may help individualize pre-activation strategies.
- Coaches and practitioners should consider individual responsiveness and keep the timing relative to the main lifts consistent to maximize the repeatability of acute effects.

Conflicts of Interest: The author of the article declare that there are no personal or financial conflicts of interest related to this study.

Authorship Contribution Statement: Study design, Data Collection, Statistical Analysis and Manuscript Preparation- MV

Generative AI Disclosure: The author used generative AI tools to assist with language editing and text refinement. All scientific interpretations, data analyses, and conclusions were developed solely by the author.

Ethics Approval

Ethics Committee: Gaziantep University Sports and Health Ethics Committee
Date: 06.16.2025
Protocol number: 569375

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