



Effects of Weighted Drop Jump Warm-up on Swim Start Performance of Adolescent Swimmers

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Abstract

The purpose of this study was to investigate whether drop jump warm-up (DW) protocols with varying loads (0%, 5%, and 10% body weight) are effective in enhancing swim start performance compared to a conventional warm-up (CW) routine for youth swimmers. A total of 23 middle and high school swimmers (age: 16.61 ± 1.64 years, height: 1.73 ± 0.07 m, weight: 64.87 ± 8.82 kg, athletic experience: 7.04 ± 2.65 years) participated in this study. They completed swim start trials after both their CW and DW, respectively, in randomized order. Kinematic variables, including entry and take-off angle, horizontal flight distance and velocity, and starting time, were analyzed using high-speed camera motion data. In addition, an inertial measurement was used to measure underwater pelvic motion during dolphin kicking, including the main frequency of pelvic angular velocity. The CW resulted in faster underwater speeds and shorter total start times compared to the DW. Furthermore, during underwater dolphin kicking, the main frequency of pelvic angular velocity in the medio-lateral axis following the CW was higher than after the DW. However, the only variable that improved with the DW was the take-off horizontal distance, which was longer than with the CW. No significant differences were found between drop jump conditions (i.e., 0%, 5%, and 10% extra body weight). Conclusively, the CW routines appear to be more effective, and the DW did not yield performance improvements, regardless of the load applied, except for take-off horizontal distance for adolescent swimmers. Future studies need to consider other warm-up protocols that account for individual characteristics and the biomechanical validity of underwater dolphin kicking movements.

Key words: warm-up, swim start, drop jump, performance, adolescent swimmers

Introduction

The swim start is a crucial component of competitive swimming, especially in sprint events where performance differences are often decided within the first few meters of the race. Because of the high-

intensity and explosive nature of the movement, minimizing the duration of the start phase is recognized as a critical factor by both coaches and sports scientists striving to maximize competitive performance. Researchers have investigated biomechanical and physiological factors influencing swimming start performance, highlighting key variables such as take-off velocity, take-off and entry angles, underwater trajectory, and 10-meter entry time (Tor et al., 2015). Based on these findings, various training interventions

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have been developed and applied to specifically target and improve these performance determinants (Waddingham et al., 2021). Among these interventions, plyometric training has been shown to enhance neuromuscular function, thereby increasing take-off power and improving start performance in competitions (Bishop et al., 2009). In addition, warm-up protocols play a crucial role in preparing athletes for competition by elevating core temperature, enhancing neural activation, and optimizing muscle-tendon function (Bishop, 2003).

Among various warm-up strategies, plyometric exercises such as drop jumps have demonstrated potential for acutely enhancing explosive movements through mechanisms collectively known as acute neuromuscular enhancements. These mechanisms include increased muscle-tendon stiffness, enhanced motor unit recruitment, and faster cross-bridge cycling, all of which contribute to greater force production in dynamic tasks (Li et al., 2023). Drop jumps, which utilize the stretch-shortening cycle, have been studied as effective pre-performance activities due to their ability to elicit acute power enhancements (Byrne et al., 2021). When combined with extra loadings (e.g., 0% to 10% of body weight via a weighted vest), drop jumps — which stimulate greater neuromuscular activation while minimizing fatigue — are potentially effective in improving subsequent explosive movements such as sprinting or jumping (Maloney et al., 2014).

Although drop jump warm-ups have demonstrated performance benefits in land-based sports, their application in aquatic sports, such as swimming starts, remains underexplored. Previous studies investigating drop jump or loaded drop jump protocols in swimming have focused exclusively on adult athletes (Wilson et al., 2013). While similar protocols have been examined in youth athletes participating in sports like soccer and weightlifting (Haris et al., 2021; Werfelli et al., 2021), research specifically targeting youth swimmers is scarce (Đurović et al., 2022). This gap is particularly important because warm-up strategies proven effective in adults may not yield the same benefits in younger athletes due to age-related differences in physiological and

neuromuscular development. Consequently, there is a clear need to investigate age-appropriate warm-up protocols to ensure their effectiveness and safety for adolescent swimmers.

To address these gaps, the present study aimed to investigate the acute effects of weighted drop jump warm-up protocols on swim start performance in youth competitive swimmers. This study established two primary hypotheses. Our initial hypothesis proposed that a drop jump warm-up (DW) intervention would lead to greater improvements in swimming start performance compared to a conventional warm-up (CW). Our second hypothesis suggested the existence of an optimal loading condition within different DW protocols that would maximize start performance. To test this hypothesis, we implemented four distinct warm-up conditions with adolescent swimmers: the conventional warm-up that athletes typically perform, a drop jump warm-up without extra weight, and drop jump warm-ups with 5% and 10% added body weight.

Methods

Participants

Twenty-three middle and high school swimmers (19 males and 4 females; mean age: 16.61 ± 1.64 years; height: 1.73 ± 0.07 m; weight: 64.9 ± 8.82 kg; swimming experience: 7.04 ± 2.65 years) participated in this study. They specialized in freestyle ($n = 12$), backstroke ($n = 3$), breaststroke ($n = 2$), butterfly ($n = 5$), and individual medley ($n = 1$). All participants were fully informed of the study's purpose, procedures, and potential risks before participation and signed an informed consent form. The study protocol was approved by the university's Institutional Review Board.

Experimental Setup

Swim start performance was evaluated by dividing the motion into two distinct phases. The first phase (1st P) included the movement sequence from the initiation of the start until water entry. This phase was recorded

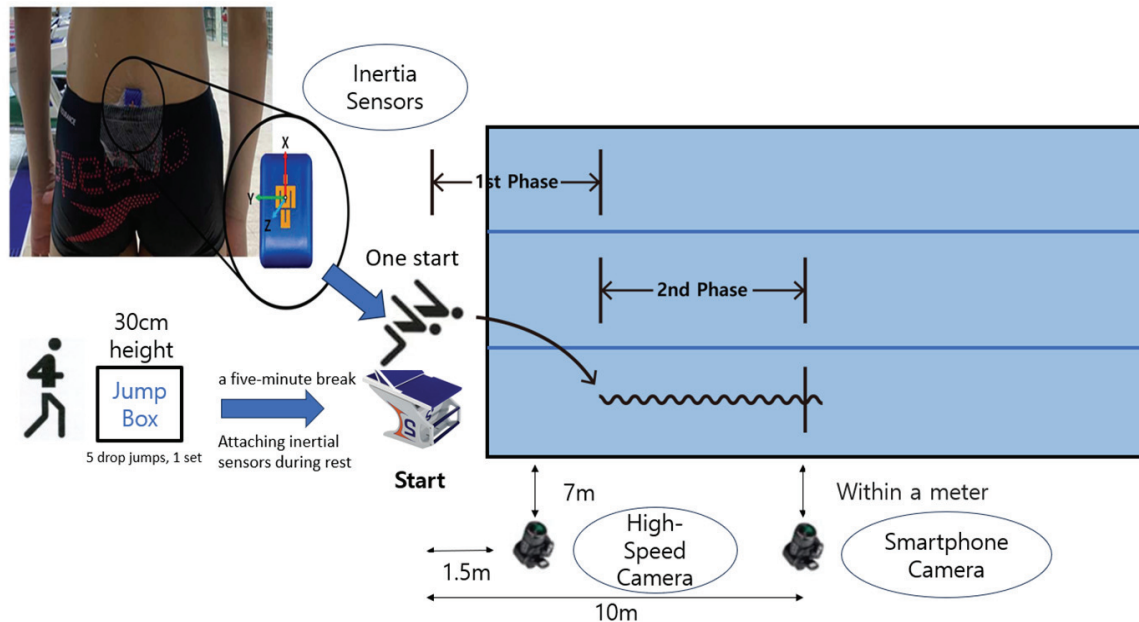


Figure 1. Experimental protocol and measurement setup for assessing swim start performance.

using a high-speed camera (Exilim EX-F1, Casio, Japan) operating at a sampling rate of 300 frames per second. The second phase (2nd P) encompassed the underwater dolphin kick performed immediately after water entry, extending to the 10-meter mark. Motion data for 2nd P were collected using an inertial measurement unit (IMU) sensor (Blue Trident, Vicon, UK) attached to the back side of the swimmer's pelvis, sampled at 228 Hz (Figure 1). The X-axis was defined as the forward direction of the swimmer's movement underwater, while the Y-axis represented the medio-lateral (M-L) axis of the body, corresponding to the axis of pelvic pitching motion during underwater movement. Additionally, total movement time covering both phases was recorded using a smartphone camera (Galaxy S22, Samsung, Korea) positioned at the 10-meter mark. Video calibration was performed before and after the data collection sessions using a custom-made calibration frame constructed from fabric material. This frame featured a grid pattern with 0.5-meter spacing and measured 5.44 meters in height and 2.2 meters in width. The high-speed camera for the 1st P was positioned 7 meters from the pool's edge, providing an optimal field of view to capture the swimmer's motion from

the starting block to water entry.

Experimental Procedures

This study employed a repeated-measures, within-subjects design to investigate the acute effects of four different warm-up conditions on swim start performance: conventional warm-up (CW), drop jumps warm-up (DW) without additional weight (0 BW), and DWs with 5% (5 BW) and 10% (10 BW) added body weight. All warm-up conditions were randomly assigned in a counter-balanced order, with a minimum of 48 hours separating each testing session. The experiments were conducted in a 50-meter indoor swimming facility equipped with starting blocks. At the start of each session, participants completed the assigned warm-up protocol. The conventional warm-up referred to each swimmer's habitual pre-competition routine, which typically included dynamic stretching of major joints (such as ankle and shoulder rotations), neural activation or tactile stimulation by slapping the skin, and light aerobic activities (e.g., on-the-spot jumping).

For the overweight drop jump warm-up conditions, participants performed one set of five trials of drop jump from a 0.3 m-high box while wearing a weighted



Figure 2. Drop jump warm-up protocol with a weighted vest.

vest (0%, 5%, or 10% of body weight), with 15 seconds of rest between jumps. A 30 cm platform was created by stacking two 15 cm step boxes. To ensure a consistent drop height, a reference rope was set at 30 cm. Participants stepped forward with one foot over the rope before dropping from the platform. Immediately upon landing, they performed a maximal vertical jump. Arm swing was allowed to maximize performance during the jump. Following the warm-up, a five-minute passive rest period was provided, based on prior evidence suggesting optimal recovery for post-activation performance enhancement (Bishop, 2003; Gray et al., 2002). The durations of DWs and resting intervals were set equal to those of CW conditions. After the rest period, participants completed a single swim start trial with maximal efforts.

Data Processing and Statistical Analysis

After data collection, video analysis of motion captures and signal processing of IMU sensor data were performed. High-speed camera video footage was used to digitize key anatomical landmarks in video analysis software (V1 Pro, V1 Sports, Michigan, USA), enabling the calculation of angles, distances, and velocity parameters during the swim start phase. The primary performance variables from motion video footage were

take-off and entry angles, take-off horizontal distance, average horizontal velocities of 1st P and 2nd P, and phase times, including total movement time (addition of 1st and 2nd Ps). IMU sensor data were filtered and smoothed using standard signal processing techniques to remove noise and improve measurement accuracy in numerical analysis software MATLAB® (Version 2015b, The MathWorks Inc., Natick, MA, USA). A 4th-order Butterworth low-pass filter with a cutoff frequency of 15 Hz was used. After calculation, peak accelerations and angular velocities of the pelvis, and frequency domain features during the underwater kicking phase (phase 2) were extracted. Main frequency of M-L axis angular velocity indicates the frequency of pelvic pitching motions per second.

All statistical analyses were performed using SPSS (v. 29.0, IBM, New York, USA). Descriptive statistics (mean $\pm$ SD) were calculated for all dependent variables. For the first hypothesis, a one-way ANOVA with planned contrasts was conducted to compare the CW against three DW conditions, using contrast weights of 3 (conventional) and -1 (for 0%, 5%, and 10% drop jump conditions, respectively). For the second hypothesis, a repeated-measures one-way ANOVA was used to compare performance across three DW conditions. Statistical significance was set at .05.

Results

Comparison of Start Performance Between the CW and DWs

Descriptive statistics for the kinematic variables observed during the swimming start under the two warm-up conditions—conventional warm-up and weighted drop jump warm-up—are presented in Table 1. The contrast analysis revealed significant differences in the horizontal distance of the 1st P, average horizontal velocity of the 2nd P, and total movement time ($p < .05$). Specifically, the horizontal distance of the 1st P was significantly longer following the DW compared to the CW. In contrast, the average horizontal

velocity of the 2nd P was significantly faster after the CW than after the DW. Furthermore, the total movement time was significantly shorter following the CW compared to the DW protocols. No other kinematic variables showed statistically significant differences between the two conditions.

IMU sensor-derived variables comparing the conventional and drop jump warm-ups are presented in Table 2. The analysis identified a significant difference in the main frequency of the mediolateral (M-L) axis angular velocity ($p < .05$), with the CW resulting in a significantly higher main frequency of the 2nd P than the DW. No other IMU variables showed statistically significant differences between the two warm-up protocols.

Table 1. Kinematic performance variables between CW and DW conditions [Mean(SD)]

	CW	DW	<i>t</i>	<i>p</i>	Effect Size
Take-off angle (°)	35.00 (6.39)	33.73 (6.79)	0.762	.448	0.550
Entry angle (°)	36.96 (4.35)	36.99 (4.83)	-0.025	.980	-0.018
Horizontal distance (1st Phase) (m)	2.74 (0.35)	2.90 (0.28)	-2.218*	.029*	-1.602
Horizontal avg. velocity (1st Phase) (m/s)	10.22 (2.25)	10.33 (2.25)	-0.196	.845	-0.142
Horizontal avg. velocity (2nd Phase) (m/s)	2.43 (0.32)	2.22 (0.25)	3.122**	.002**	2.255
Ground Contact Time (s)	0.494 (0.050)	0.503 (0.048)	-0.779	.438	-0.562
1st Phase Time (s)	0.297 (0.070)	0.296 (0.073)	0.029	.977	0.021
2nd Phase Time (s)	3.041 (0.433)	3.253 (0.478)	-1.892	.062	-1.366
Total Movement Time (s)	3.823 (0.431)	4.052 (0.477)	-2.039*	.044*	-1.473

* $p < .05$, ** $p < .01$

Table 2. IMU sensor-derived variables in the 2nd phase between CW and DW conditions [Mean(SD)]

		CW	DW	<i>t</i>	<i>p</i>	Effect Size
Acceleration in the forward direction (m/s ²)	Maximum	19.50 (6.24)	21.25 (7.57)	-1.073	.286	-0.715
	Minimum	-12.81 (3.49)	-12.04 (3.40)	-1.011	.314	-0.675
	Range	32.31 (8.21)	33.30 (10.30)	-0.441	.660	-0.294
Angular velocity in M-L axis (°/s)	Maximum	217.53 (100.61)	214.59 (50.89)	0.206	.837	0.138
	Minimum	-194.37 (114.65)	-177.05 (44.67)	-1.079	.283	-0.720
	Range	411.90 (208.17)	391.63 (84.28)	0.695	.489	0.464
Main Frequency in M-L axis (Hz)		2.43 (0.77)	2.18 (0.35)	2.146*	.034*	1.432

**p*<.05

Effect of Different Loading Conditions on Start Performance within Drop Jump Warm-up

The descriptive statistics comparing the kinematic variables during the swimming start under different drop jump conditions (additional 0%, 5%, and 10% of body weight) are shown in Table 3. The results showed no statistically significant differences among the three warm-up conditions in terms of take-off angle, entry angle, horizontal distance, velocity, or movement times.

Similarly, Table 4 presents the IMU sensor-derived variables during the 2nd P. The analysis revealed no statistically significant differences among the three different DWs for any of the IMU variables assessed.

Discussion

This study aimed to determine whether an overweight drop jump warm-up could enhance swim start performance in youth swimmers aged 14 to 19 compared to a conventional warm-up. The hypothesis was based on previous research suggesting that

appropriately loaded drop jumps could activate the neuromuscular system through post-activation potentiation (PAP), potentially leading to improved subsequent performance (de Poli et al., 2020; Seitz & Haff, 2016; Abbes et al., 2018; Al Kitani et al., 2021). The experimental design of this study differed from previous studies in the following key aspects. First, unlike prior studies that rarely validated findings with adolescent participants, this study specifically involved subjects within the adolescent age range. Second, the task employed was not a simple vertical jump, which is commonly used to directly examine the effects of post-activation potentiation (PAP), but rather the swim start—a complex movement that includes a jumping component but also involves other dynamic and sport-specific elements. The DW showed improvement only in the horizontal distance of the 1st phase compared to the CW. Contrary to expectations on the first hypothesis, the CW revealed better performance in average horizontal velocity of the 2nd P, total movement time, and the main frequency of the angular velocity in the M-L axis (the 2nd P).

The absence of significant differences in dominant performance variables between the two warm-up

Table 3. Kinematic performance variables across different drop jump loading conditions (additional 0%, 5%, and 10% body weight) [Mean(SD)]

	0% BW	5% BW	10% BW	<i>F</i>	<i>p</i>
Take-off angle (°)	33.48 (6.91)	33.96 (7.51)	33.74 (6.96)	0.873	.425
Entry angle (°)	37.30 (4.51)	36.57 (4.67)	37.09 (5.32)	0.791	.460
Horizontal distance (1st Phase) (m)	2.87 (0.27)	2.94 (0.29)	2.89 (0.29)	0.198	.821
Horizontal avg. velocity (1st Phase) (m/s)	10.35 (2.17)	10.26 (2.12)	10.37 (2.47)	1.100	.330
Horizontal avg. velocity (2nd Phase) (m/s)	2.24 (0.26)	2.20 (0.24)	2.22 (0.26)	0.481	.621
Ground Contact Time (s)	0.497 (0.044)	0.502 (0.051)	0.510 (0.049)	0.467	.630
1st Phase Time (s)	0.295 (0.072)	0.300 (0.073)	0.294 (0.075)	1.651	.204
2nd Phase Time (s)	3.257 (0.478)	3.252 (0.472)	3.251 (0.484)	0.265	.768
Total Movement Time (s)	4.048 (0.473)	4.054 (0.474)	4.054 (0.485)	0.642	.531

* $p < .05$

Table 4. IMU sensor-derived variables across different DW conditions (additional 0%, 5%, and 10% body weight) [Mean(SD)]

		0% BW	5% BW	10% BW	<i>F</i>	<i>p</i>
Acceleration in the forward direction (m/s ²)	Maximum	22.22 (7.16)	21.32 (8.19)	21.51 (8.80)	1.401	.251
	Minimum	-12.46 (3.96)	-11.89 (3.25)	-11.99 (3.62)	0.831	.373
	Range	34.68 (10.54)	33.21 (10.80)	33.50 (11.89)	1.564	.225
Angular velocity in M-L axis (°/s)	Maximum	215.03 (56.22)	203.95 (44.47)	206.35 (45.34)	0.924	.348
	Minimum	-171.88 (37.10)	-175.78 (46.11)	-174.05 (53.12)	0.164	.689
	Range	386.91 (82.93)	379.73 (74.07)	380.40 (88.37)	0.156	.697
Main Frequency in M-L axis (Hz)		2.20 (0.33)	2.19 (0.40)	2.17 (0.35)	0.137	.715

* $p < .05$

conditions may be attributed to several reasons. Firstly, it could be partially ascribed to the inherent characteristics of the swim start motion. The swimming start comprises multiple phases—such as the block phase, flight phase, water entry, and underwater propulsion—making it challenging to isolate the specific impact of additional loading on each phase. Secondly, individual differences in fatigue resistance and responsiveness to post-activation potentiation (PAP) may have attenuated the effects of the DW condition. Specifically, despite exhibiting a longer horizontal distance during the 1st phase, the inferior performance observed in terms of average horizontal velocity of the 2nd phase and total movement time—compared to the CW condition—suggests that the participants may not have fully benefited from the warm-up or PAP stimuli. The findings of this study partially align with those of Cuenca-Fernández et al. (2020), who reported that while resistance-based warm-ups can enhance start performance, they may adversely affect subsequent 50-meter performance due to accumulated fatigue.

Another potential explanation for the observed results is the muscular fatigue likely induced by the execution of overweight drop jumps, although direct verification through electromyographic (EMG) analysis was not conducted in this study. Repetitive stretch-shortening cycle exercises may enhance immediate jump performance but can also cause fatigue, leading to decreased lower limb muscle activation and impaired performance (Lesinski et al., 2016). This study assumed the optimal time window for the post-activation potentiation (PAP) effect as a 5-minute resting time when designing the warm-up-to-start transition for adolescent athletes, but the fatigue induced by overweight drop jumps may have offset the benefits of PAP.

Additionally, inconsistencies in previous research regarding optimal recovery time, drop jump height, and weight conditions for maximizing the PAP effect posed challenges in study design. Wilson et al. (2013) suggested that a recovery period of 7–10 minutes is appropriate, whereas Waddingham et al. (2021) found that 6 minutes was effective in improving swimming

start performance. Although this study incorporated insights from these studies when setting experimental conditions, identifying significant differences based on weight conditions remained challenging.

In this study involving youth swimmers aged 14 to 19, the absence of significant improvements in swim start performance following the overweight drop jump warm-up may be partially attributed to the ongoing neuromuscular development characteristic of adolescents. During adolescence, the neuromuscular system is still maturing, which can influence the efficacy of interventions like post-activation potentiation (PAP). Compared to adults, adolescents generally exhibit lower muscle-tendon stiffness and reduced efficiency in neuromuscular coordination, which can lead to a delayed or diminished response to potentiation stimuli (Mersmann et al., 2017). Furthermore, their recovery capacity from high-intensity loads such as weighted plyometric exercises may be limited, making them more susceptible to fatigue-related performance declines (Falk & Dotan, 2006). These developmental factors should be taken into account when applying PAP-based warm-up protocols to youth athletes, as the optimal balance between potentiation and fatigue may differ significantly from that of adults (Sanchez-Sanchez et al., 2018).

Another potential factor is the negative transfer effect caused by differences in movement characteristics between the warm-up and the actual swimming start. The drop jump is a discrete motor skill with a clear beginning and end, whereas the underwater dolphin kick is a continuous motion requiring rhythmic, repetitive movements. Studies on motor control and learning suggest that transfer between discrete and continuous skills is limited (Levac et al., 2019; Woltz et al., 2000).

This study aimed to identify the optimal loading condition for enhancing swim start performance. Based on findings from previous research (Halteman et al., 2018), DWs with additional loads of 0%, 5%, and 10% of body weight were implemented. However, contrary to the initial hypothesis, no significant differences were observed in swim start performance across the different

loading conditions. This suggests that the loading conditions employed may not have been optimal for maximizing swim start performance. The findings of this study partially align with the study by Halteman et al. (2018), which reported that adding 5 to 15% external load during drop jumps did not affect jump height, mean velocity, or mean power.

This study has a couple of limitations. First, the variability of the conventional warm-up (CW) protocol poses a challenge. Because participants favored different CW styles, we could not standardize a specific type for the control condition. This inherent variability may have reduced the study's internal validity. While our intention was to enhance external validity by allowing participants to perform the CW as they would in a competitive setting, we speculate that narrowing the CW conditions might have been beneficial. A more constrained CW protocol could have improved statistical power and allowed for a clearer focus on the hypothesized outcomes, thereby strengthening internal validity.

Second, limitations existed in applying variables uniformly across all participants, such as drop jump height, recovery time, and exercise intensity (absolute percentage of body weight). Because adolescents are in a period of rapid growth, their strength and power develop significantly year by year. We regret not being able to implement individually tailored experimental conditions based on personal characteristics (e.g., strength, power, fatigue recovery ability) or swimming style. If follow-up research is conducted in the future, it will be essential to incorporate personalized experimental conditions according to individual characteristics.

Future investigations could also examine whether combining sport-specific dynamic movements with moderate plyometric loading can achieve a better balance between potentiation and fatigue. Longitudinal studies assessing the chronic adaptation effects of repeated PAP interventions in youth swimmers would further advance understanding of optimal warm-up strategies for this population.

Conclusion

This study aimed to determine whether an overweight drop jump warm-up protocol is better than a conventional warm-up in terms of swim start performance for adolescent swimmers. After data collection and analysis, the following conclusions were induced.

First, when comparing kinematic variables between warm-up protocols, the drop jump warm-up was superior only for the horizontal distance of the 1st phase, while no significant differences were observed, or the conventional warm-up showed better performance, for the remaining variables. The conventional warm-up showed a faster underwater average velocity, a reduced movement up to the 10-m mark, and a higher pelvic pitching frequency of the dolphin kick.

Second, when comparing kinematic variables among the three different overweight drop jump warm-up protocols (additional 0%, 5%, and 10% body weight), no statistically significant differences were observed in any variables between conditions.

In conclusion, implementing an overweight drop jump warm-up protocol to enhance swim start performance in youth swimmers aged 14 to 19 may not be effective. In fact, a conventional warm-up routine might yield better results. Future studies investigating the acute effects of warm-ups should comprehensively consider various complex factors, including an adolescent athlete's individual physical characteristics, muscle development, muscle fatigue, weight selection, exercise intensity, jump height, recovery time, and technical aspects of movement.

Author Contributions

Seokjin Choi and Youngkwan Kim contributed equally to all stages of the study, including conceptualization, data collection, data analysis, drafting of the original manuscript, revision, and responses to the editors' requests.

Conflict of Interest

The authors declare no conflict of interest.

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