DOI: 10.51558/1840-4561.2026.23.1.5

IMMEDIATE EFFECTS OF TOTAL BODY RESISTANCE EXERCISE (TRX)-BASED WARM-UP ON CRAWL-STROKE SPEED MUSCLE STRENGTH AND SHOULDER RANGE OF MOTION IN YOUNG COMPETITIVE SWIMMERS

Kurusart Konharn[1,2], Teerachpan Maneetam[3], Changai Zhang[4], Paramaporn Sangpara[5]

[1] School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University, Thailand
[2] Research Center in Back, Neck, Other Joint Pain and Human Performance (BNOJPH), Khon Kaen University, Khon Kaen, Thailand
[3] Exercise and Sport Sciences Program, Graduate School, Khon Kaen University, Thailand
[4] School of Physical Education, Liupanshui Normal University, Guizhou, China.
[5] Program in Applied Statistics, Faculty of Science and Technology, Rajabhat Mahasarakham University, Mahasarakham, Thailand

Original scientific paper

Abstract
The aim of the research was to investigate the immediate effects of a TRX-specific warm-up on crawl stroke speed, muscle strength, and shoulder range of motion (ROM) in young competitive swimmers. Sixteen young competitive swimmers (mean age: 11.31 ± 1.6 years) participated in this study. Participants were matched based on crawl stroke speed and randomly assigned into two groups: (1) the intervention group, which performed a TRX-specific warm-up (n = 8), and (2) the control group, which performed a traditional swimming warm-up (n = 8). Muscle strength and shoulder range of motion (ROM) were measured immediately after the intervention. Following a 10-minute rest period, participants performed 50- and 100-meter crawl stroke swims to assess swimming speed. Results showed the intervention group significantly improved their 100-meter swimming speed and demonstrated an increase in left shoulder internal rotation range of motion ($p < 0.05$). However, no significant differences were observed in 50-meter swimming speed or muscle strength parameters. The control group showed no significant changes in any of the measured variables. Findings suggest incorporating a TRX-specific warm-up may enhance 100-meter swimming performance in young competitive swimmers. Therefore, including TRX exercises in pre-competition warm-ups is recommended to improve swim performance.
Key words: acute effects, freestyle stroke, muscle strength, suspension training, youth swimmers

INTRODUCTION
Swimming enjoys significant global popularity, ranking among the leading international sports and representing the second most participated sport in the Olympic Games (Cengiz & Coşkun, 2023). Unlike many other forms of physical exercise, swimming takes place in an aquatic environment, which introduces unique gravitational and resistive forces (Varma & Gokhale, 2021). The front crawl, also known as freestyle, was the first swimming stroke introduced in competition and remains the most commonly used due to its superior speed. During this stroke, swimmers alternately rotate their arms forward while performing a flutter kick with the legs (Kwok et al., 2021). In competitive swimming, race outcomes are determined by time, with even millisecond differences potentially affecting final rankings. As such, swimming speed is a critical determinant of performance and competitive success. Achieving high levels of physical fitness is particularly important in sprint events, where rapid energy generation and muscular power are essential for optimal performance. Environmental factors, such as water temperature, significantly impact peripheral vascular physiology and, in turn, the overall function of the cardiovascular system (Khodaee et al., 2016). For short-distance sprint events (e.g., 50 meters), swimmers must emphasize improving their ability to rapidly produce energy through the phosphocreatine system. In addition, developing anaerobic energy production is crucial, particularly for middle-distance events (100–200 meters). This includes enhancing anaerobic enzyme activity and increasing the body's buffering capacity or lactate tolerance, both of which are essential for sustaining high-intensity performance (Khodaee et al., 2016). Refining warm-up routines in swimming is essential for enhancing metabolic efficiency by optimizing propulsive forces while reducing drag (Neiva et al., 2014). Although numerous studies have reported performance improvements following various warm-up protocols, review articles reveal conflicting findings, with some researchers observing no significant benefits from specific warm-up strategies. This inconsistency highlights the need for a thorough evaluation of warm-up effectiveness and the refinement of their design. Notably, the efficacy of warm-up techniques in competitive swimming remains relatively underexplored in the

scientific literature, indicating a need for further research to clarify their potential performance benefits.

In general, physical activity, warm-ups are primarily performed to prepare the body for more intense exercise. In sports, warm-ups are used to ready the body for competition by gradually activating physiological systems. Warming up increases heart rate and blood flow, allowing greater oxygen delivery to the working muscles, which enhances movement efficiency (Bishop, 2003). Additionally, warm-ups help loosen muscles and reduce stress on tendons and joints, thereby lowering the risk of injury. A well-designed, sport-specific warm-up prepares athletes both physically and mentally, contributing to improved performance. Dynamic warm-ups, which involve continuous, sport-relevant movements, are particularly effective in preparing the body for the specific demands of athletic performance. A recent systematic review examining warm-up protocols for sprint swimming performance reported the use of various warm-up strategies among swimmers and found a significant relationship between warm-up routines and performance outcomes (Czelusniak et al., 2021). Shoulder pain is the most common musculoskeletal issue among swimmers and is often associated with either hypomobility or hypermobility of the shoulder complex (Mise et al., 2022; Neiva et al., 2014; Rinonapoli et al., 2023). Fortunately, most cases can be effectively managed through rehabilitation interventions, targeted strengthening programs, and correction of swimming stroke mechanics. Implementing a structured regimen of muscle-strengthening exercises that focus on the rotator cuff, scapular stabilizers, and core muscles—including the abdominal and lower back regions—has proven beneficial both as a preventive measure and as part of rehabilitative strategies to support shoulder health (Yoma et al., 2022). Moreover, swimming requires balanced muscular development and symmetry in muscle strength to maintain proper technique and prevent injury. Despite its importance, the most effective warm-up protocol—particularly for young athletes—remains unclear. Active warm-ups, which involve physical movement, can be performed either in the water or on land, with the latter commonly referred to as a dryland warm-up. Dryland exercises have become an integral component of pre-competition routines across all age groups and competitive levels. These programs often emphasize strengthening the shoulder's external and internal rotator muscles, which are critical for stroke mechanics and shoulder stability (Della Tommasina et al., 2023). However, previous studies investigating various warm-up approaches have reported inconsistent and inconclusive results regarding their effectiveness on performance outcomes. Total Resistance Exercise (TRX) is a form of suspension training that enables users to exercise across three planes of motion. It allows for a wide range of functional movements, with resistance intensity adjustable by modifying body position and joint angles (Assar et al., 2020). Previous studies consistently show that TRX exercises effectively engage stabilizing muscles across multiple joints, with a particular emphasis on core muscle activation. This results in improved coordination and strength in both the upper and lower body (Assar et al., 2020; Fayazmilani et al., 2022). Due to its adaptable nature and low-impact design, TRX has gained popularity in both rehabilitation and general fitness settings. The ability to easily modify resistance by adjusting body position makes it especially advantageous for athletes such as swimmers, who require joint control and functional strength. However, the effects of a TRX-based warm-up on crawl stroke speed, muscle strength, and shoulder range of motion (ROM) in young competitive swimmers remain underexplored. Therefore, the aim of this study was to investigate the immediate effects of a TRX-specific warm-up on swim speed, muscle strength, and shoulder ROM in young competitive swimmers. We hypothesized that a TRX-based warm-up would produce greater improvements in these parameters compared to a traditional warm-up without TRX.

RESEARCH METHODOLOGY

This study employed a randomized controlled trial (RCT) design and was approved by the Center for Ethics in Human Research, Khon Kaen University, in accordance with the Declaration of Helsinki (Project Number# HE602171).

Participants

Sixteen young swimmers, aged 9 to 13 years, from the public Swimming Club in Thailand, who had been training regularly (three days per week) and had at least one year of experience competing in organized regional events, were recruited for this study. Participants with any orthopedic conditions, or injuries to muscles, ligaments, tendons, joints, or bones within the past six months were excluded from the study. Ultimately, 16 participants (7 males and 9 females) met all eligibility criteria. Written informed consent was obtained from the swimming club owner, the participants' parents, and the participants themselves after providing both verbal and written explanations of the study. Then, they were assigned to two groups using a randomized matching technique based on their crawl stroke swimming speed: a control group (CON) and an experimental group (TRX). A detailed description of the sample characteristics is provided in Table 2.

Measurements

Anthropometric measurements were conducted at baseline to assess participants' physical characteristics. Body weight and height were measured using a calibrated balance beam scale, with participants standing barefoot and wearing light clothing to ensure accuracy. In addition, body composition parameters—including body fat percentage, body mass index (BMI), and resting metabolic rate—were assessed using a validated body composition monitor (Model HBF-375, OMRON Healthcare Co., Ltd., Kyoto, Japan). All measurements were performed according to the manufacturer's protocol to ensure reliability and consistency across participants. Muscle strength was assessed using a digital handheld dynamometer (MicroFET® 2, FET–Force Evaluation and Testing, Hoggan Scientific LLC, Utah, USA), which is a validated and reliable instrument for evaluating isometric muscle force. Participants were instructed to stand in an upright position with their shoulders abducted to 90 degrees and elbows flexed to 90 degrees in the frontal plane. Isometric strength measurements were taken for both shoulder internal and external rotation. During each test, participants were asked to exert maximal voluntary force against the dynamometer while maintaining the specified joint position. Standardized verbal encouragement and instructions were provided to ensure consistent effort across trials. Shoulder range of motion (ROM) was assessed using a standard manual goniometer (Baseline® Plastic Goniometer – HiRes™, Iowa, USA). Measurements were taken for both internal and external rotation of the dominant and non-dominant shoulders. Each ROM test was performed twice, and the highest value from the two trials was recorded for analysis to ensure accuracy and consistency. Following a 10-minute rest period after the ROM and muscle strength assessments, participants were instructed to perform two maximal-effort swim trials: one at a distance of 50 meters and the other at 100 meters, using the front crawl stroke. Swimming performance was assessed by recording the time (in seconds) taken to complete each distance. All swimming trials were conducted under standardized conditions to ensure comparability across participants.

Interventions

Each participant was randomly assigned to either the control group or the experimental group. The control group performed a standard warm-up protocol, as outlined in a previous study by Neiva et al. (2017) (see Table 1). In contrast, the experimental group began with a crawl-stroke–specific dynamic warm-up, followed by a TRX-based warm-up session. The TRX system, consisting of two suspension straps anchored to a fixed point (TRX; Fitness Anywhere LLC, California, USA), was used to perform four targeted exercises:

A) Hip abduction in plank (15 repetitions),

B) Hamstring curl (15 repetitions),

C) Chest press (15 repetitions), and

D) 45° Row (15 repetitions).

These exercises were described by Patil et al. (2014), that were chosen for their emphasis on core and upper/lower body muscle activation relevant to swimming performance. The total duration of the warm-up was approximately 10-15 minutes. Each TRX exercise was performed for 2 sets, with a 1-minute rest interval between sets, following a structured and consistent format across all participants in the experimental group.

Table 1. Standard warm-up protocols

Warm up	Task descriptions
300m	100m usual breathing, 100m breathing in the 5th stroke, 100m usual breathing
4 x 100m on 1:50	2 x (25m kick and 25m increased stroke length)
8 x 50 m on 1:00	98-102% of critical velocity (or 85-90% of 100m pace)
100m	Easy swim

Statistical analyses

Descriptive data for participants' baseline characteristics are presented as mean ± standard deviation (mean ± SD). All statistical analyses were performed using SPSS statistical software (version 19.0; SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated to summarize participant demographics and baseline measurements. To evaluate within-group differences (pre- vs. post-intervention), paired-sample t-tests were conducted for each outcome variable. Between-group comparisons (experimental vs. control group) were analyzed using independent-sample t-tests. A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant for all tests.

Table 2. Baseline characteristic of participants

Characteristics	Control group (CON) (n=8)	Experimental group (TRX) (n=8)	t	p-value
Age (years)	11.88±1.64	10.75±1.39	1.48	.16
Body mass (kg.)	46.66±9.98	37.23±14.85	1.49	.15
Height (cm.)	152.50±11.26	142.75±17.22	1.34	.20
Body mass index (kg/m^2)	19.55±3.36	17.48±3.21	1.26	.22
Percent fat (%)	19.60±5.67	19.89±2.60	-0.13	.89
Metabolic rate (kcal)	1172.13±201.22	885.64±439.43	1.67	.11
Body fat mass (kg.)	15.41±5.54	19.18±7.66	-1.12	.27

NOTE: Data are expressed as mean ± SD.

Table 3. Swimming speeds for 50 and 100 meters in specific warm-up and specific warm-up with TRX groups (in second)

Swimming distance	Control group		Experimental group (TRX)	
	Before (sec.)	After (sec.)	Before (sec.)	After (sec.)
50 m.	39.00 ±4.6	38.61 ±5.2	42.04 ±4.9	41.41±5.3
100 m.	89.67 ±11.0	88.20 ±10.6	98.17 ±12.1	95.61±11.9**

NOTE: Data are expressed as mean ± SD.
**Significantly different from before warm-up ($p < 0.01$).

Table 4. Changes in muscle strength and shoulder range of motion (ROM) between specific warm-up (control) and specific warm-up with TRX (experiment) group.

As shown in Table 4, there were no statistically significant differences between the control and experimental groups in changes in muscle strength across all measured shoulder rotator muscles on both the dominant and non-dominant sides ($p > 0.05$). However, swimmers in the experimental group who performed the TRX warm-up demonstrated a significant improvement in shoulder range of motion (ROM) for external rotation on both sides ($p < 0.05$). In contrast, no significant changes in ROM were observed in the control group.

Variable	Control group		Experimental group (TRX)	
	Baseline	After	Baseline	After
Muscle strength (kg.)				
Left external rotator	8.50±1.2	8.38±1.2	8.13±1.6	7.19±2.9
Right external rotator	8.88±1.3	9.06±1.2	8.13±1.3	7.81±2.5
Left internal rotator	10.25±1.0	10.06±1.2	9.38±1.7	9.31±1.9
Right internal rotator	10.13±1.6	10.25±1.5	9.13±1.9	8.94±2.8
Shoulder range of motion (°)				
External LA	91.88±13.9°	93.75±12.7°	95.50±14.1°	97.50±11.6°*
External RA	92.13±16.6°	92.94±14.3°	91.25±16.6°	94.19±12.7°*
Internal LA	75.00±18.3°	76.44±16.9°	69.25±8.1°	71.44±9.2°
Internal RA	70.00±21.4°	71.56±20.9°	70.25±7.1°	69.06±9.5°

NOTE: Data are expressed as mean ± SD.
*Significantly different from before warm-up ($p < 0.05$).

DISCUSSION

This study aimed to investigate and compare the acute effects of a TRX-based specific warm-up on crawl-stroke swimming speed, muscle strength, and shoulder ROM in young competitive swimmers. The results revealed significant improvements in 100-meter swimming speed and shoulder ROM among swimmers who performed the TRX-specific warm-up, suggesting that these enhancements may be attributed to the acute neuromuscular and biomechanical effects of the intervention. Specifically, the TRX exercises, which incorporate bodyweight resistance and functional movement patterns, may enhance dynamic joint mobility and activate key muscle groups involved in propulsion and stabilization during the swimming stroke. Improved shoulder ROM, particularly in external rotation, likely contributed to a more efficient stroke technique and extended reach, ultimately enhancing swimming efficiency over longer distances. However, no statistically significant changes were observed in the 50-meter swim speed in either group. This may indicate that the warm-up protocol, although effective for improving movement efficiency and muscular readiness, was not sufficient to induce performance gains in short-distance sprints where explosive power, anaerobic capacity, and reaction time play a more dominant role. Unlike the 100-meter event, which relies more heavily on sustained force production and technical endurance, the 50-meter sprint is characterized by a maximal, all-out effort with little room for error. In this context, the warm-up may not have adequately stimulated the phosphagen (ATP-PCr) energy system or the neuromuscular pathways required for peak velocity output. These findings align with previous literature suggesting that warm-up protocols incorporating dynamic and functional components, such as TRX, may be more beneficial for events requiring endurance and coordination rather than pure sprint performance (Takagi et al., 2023). Consistent with previous studies investigating the effects of core strength training in young adult and child swimmers, the present study found no significant improvement in 50-meter freestyle sprint time following a two session of TRX-based warm-up (Eskiyecek et al., 2020; Patil et al., 2014). One possible explanation for this finding is the short duration of the intervention, which may be insufficient to elicit meaningful changes in neuromuscular coordination and explosive power required for sprint events. Core musculature plays a vital role in swimming by maintaining a streamlined posture, enhancing body alignment, and facilitating efficient transfer of force during stroke execution. Although the engagement of core muscles can increase motor system demands and muscle activation, such benefits may only translate into performance improvements over time with repeated exposure. Interestingly, previous research by Patil et al. (2014) reported that six weeks of core strength training significantly improved 50-meter sprint performance and stroke index, without significant changes in stroke rate or stroke length. Notably, swimmers in the core training group showed nearly twice the improvement compared to those undergoing standard swim training. Similarly, in the present study, although focused on immediate effects, we observed a 1.74-fold improvement in the 100-meter performance in the TRX group compared to the control group. This suggests that even a short duration TRX-based warm-up session may produce measurable performance gains, potentially due to the activation of core stabilizing muscles and improved movement efficiency. TRX suspension exercises inherently require dynamic stabilization and the engagement of multiple muscle groups simultaneously, which may enhance both static and dynamic balance, core strength, and postural control. Incorporating TRX into a warm-up routine introduces an element of instability and functional resistance, aligning with evidence that supports the use of unstable resistance training to enhance neuromuscular activation. According to Behm and Anderson (2006), unstable resistance training can elicit significant muscle activation while reducing joint stress, offering potential benefits for both performance and injury prevention. These findings support the idea that integrating TRX exercises into pre-competition warm-up routines may not only enhance acute performance but also contribute to long-term physical development in young swimmers. Further research is warranted to examine the chronic effects of TRX training and to determine its optimal application in various swimming distances and age categories. In the context of prepubescent soccer athletes, an 8-week TRX training program has been demonstrated efficacy in improving physical fitness, as demonstrated by Fayazmilani et al. (2022). While positive effects, particularly in core muscular endurance, upper and lower body strength as well as balance gains, were observed in their study. The current study did not observe significant changes in muscle strength in either group, suggesting that the short duration of the intervention may have limited its impact on force production. However, the observed improvement in ROM in the experimental group may be attributed to the TRX warm-up, which likely facilitated greater joint mobility through the enhancement of both concentric and eccentric muscle contractions. Additionally, TRX exercises predominantly stimulate muscles through eccentric contractions, which have been shown to produce greater physiological adaptations than general strengthening exercises. Eccentric training typically induces more significant changes in muscle architecture and neuromuscular control compared to concentric training (Pakosz et al., 2023). As a result, it is expected to enhance postural stability, improve joint mobility, and increase motor control. However, in the present study, a slight decrease in muscle strength was observed in the TRX group. This unexpected finding may suggest that certain muscle groups were overstretched during suspension-based TRX exercises, potentially compromising optimal muscle contraction (Kruse et al., 2021). Despite this, the study revealed several noteworthy outcomes, offering valuable insights into the acute muscular adaptations of the shoulder complex following a TRX-based warm-up. These findings highlight both the potential benefits and limitations of incorporating suspension training into pre-competition routines for young athletes.

Previous studies have demonstrated that long-term resistance training in professional handball players can lead to significant improvements in peak torque of both internal and external shoulder rotation (Maroto-Izquierdo et al., 2022). Moreover, Batalha et al. (2020) investigated the acute effects of elastic band resistance exercises on shoulder internal and external rotation strength in young swimmers. Participants used different-resist elastic bands, with blue bands assigned to female participants and black bands to male participants. The exercise protocol consisted of two sets of 20 repetitions, with the final set performed to volitional fatigue. Although peak torque of both the shoulder internal and external rotators showed a slight decrease following the intervention compared to baseline, this difference was not statistically significant. However, in the present study, improvements were observed only in the shoulder external rotators. One possible explanation for this discrepancy is that during TRX exercises, the shoulder internal rotators undergo a stretching phase while the external rotators are actively engaged in contraction. This differential muscle activation may selectively enhance strength in the external rotators.

The primary strength of our study lies in its pioneering investigation of TRX exercises as a warm-up modality among young competitive swimmers, coupled with an evaluation of swimming speed over 50- and 100-meter distances, thereby simulating a realistic competition environment. The limitations must be acknowledged. First, the assessment focused exclusively on immediate, short-term effects, leaving the long-term sustainability of the observed benefits unclear. Second, as the participants were children, hormonal fluctuations during the study period may have influenced the results. Despite these limitations, our findings offer promising evidence for young swimmers and their coaches regarding the integration of TRX into conventional warm-up routines. This combined approach appears to enhance both swimming speed and shoulder flexibility. Overall, our study contributes valuable insights into warm-up protocols for young swimmers, potentially guiding future training strategies.

CONCLUSION

The immediate improvements in 100-meter crawl speed and shoulder range of motion following TRX warm-up suggest it is an effective method to enhance performance in young competitive swimmers. While no significant changes were seen in short-distance speed or muscle strength, TRX warm-ups may improve neuromuscular activation and joint mobility. Coaches and athletes can incorporate TRX exercises into pre-competition warm-up routines to optimize performance and reduce injury risk. However, further studies are needed to explore the long-term benefits of this approach.

Practical implications

The integration of TRX exercises into warm-up routines offers a practical and efficient strategy for enhancing shoulder mobility and preparing young swimmers for the demands of competitive swimming. Coaches can use TRX training to specifically target muscle groups involved in stroke mechanics, promoting better joint stability and movement control. This warm-up modality may also serve as a preventive measure against common shoulder injuries by improving muscular balance and flexibility. Furthermore, the adaptability of TRX allows for individualized intensity adjustments, making it suitable for swimmers with varying levels of strength and experience. Adopting such innovative warm-up techniques could help optimize training outcomes and support long-term athlete development.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgment

This study has received funding support from the Research Center in Back, Neck, Other Joint Pain and Human Performance (BNOJPH), Khon Kaen University, Thailand. The authors are grateful to the participants who took part in the study.

Additionally, this research is dedicated to the memory of Mr. Teerachpan Maneetam, whose unwavering dedication and determination continue to inspire us.

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Corresponding Authors
Kurusart Konharn, PhD, PT.
School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University 123, Mittaphap Road, Muang, Khon Kaen 40002, THAILAND
Email address: kuruko@kku.ac.th