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Examining the Effect of Specialized Core Muscle Training on Kinematic Parameters and Performance in 50m Front Crawl Swimming: A Study on Elite Indian Para-Swimmers

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ABSTRACT
This study investigates the effects of a 6-week specialized training program aimed at strengthening core muscles to enhance specific aspects of swimming races among Indian para-swimmers. Sixteen male para-swimmers in the S9 & S10 categories, aged 23 to 30, participated in the research. Randomly assigned to either the experimental group (EG, n = 8) or the control group (CG, n = 8), both groups followed the same water training schedule in terms of volume and intensity. The EG, however, engaged in additional specific core muscle training. During the 50m front crawl swim, kinematic parameters related to the start, turn, and swimming techniques were meticulously recorded using a video camera system. Both groups exhibited a slight increase in the flight phase at the start (EG = 0.06 m, 1.8%; p = 0.088; CG = 0.08 m, 2.7%; p = 0.013). Significant improvements were observed in the EG, including a 0.1s reduction (-28.6%; p < 0.001) in the time to cover 5m after the turn and a 3.56 m/s increase (23.2%; p = 0.001) in average swimming speed over this distance. The EG also demonstrated a statistically significant improvement of 0.3s (-1.2%, p = 0.001) in 50m front crawl swimming performance. These findings emphasize the significance of integrating isolated core muscle training as a valuable supplement to the standard training regimen for para-swimmers. The improvements in key kinematic parameters and overall performance underscore the potential benefits of targeted core training in enhancing the competitive edge of para-swimmers.
Keywords: *Front crawl, Core Muscle, swimming, Indian Para-swimmers, water training.*

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INTRODUCTION

The significance of strength and muscular power in achieving success in swimming-related sports cannot be overstated. Among the crucial elements influencing the effectiveness of training processes, appropriate conditioning of the abdominal muscles and torso emerges as a key determinant [1,23]. The primary objective in swimming competitions is to cover a specified distance in the shortest possible time, predominantly accomplished through optimal body positioning in the water and minimizing resistance [2–5]. Numerous publications underscore the integration of core muscle exercises in swimming training programs, highlighting their role in enhancing stabilizing muscles, which, in turn, contributes to greater limb strength [4,6,7]. The concept of core muscles has evolved to encompass the rectus abdominis, latissimus dorsi, gluteus maximus, and trapezius [6,3,10].

Achieving and maintaining proper body positioning during swimming, including during starts, turns, and overall distance, is paramount for efficiency and reduced travel distance [24]. The coordination and strengthening of muscles responsible for correct body positioning constitute the foundation of effective swimming technique [9,12]. This involves aligning various body segments—head, shoulder girdle, torso, pelvis girdle, and legs—almost linearly to minimize water resistance [11,13,14]. Given the inherently unstable aquatic environment, exemplary core muscle engagement becomes crucial, and any lack of stability implies potential deficits in one or more muscles, resulting in significant time losses. In addition to reducing resistance, a high and stable body position optimizes the power exerted by the upper and lower limbs [8,15,16].

The literature provides substantial evidence supporting the efficacy of dry-land training in enhancing swimming performance [17,18]. Patil et al.'s research demonstrated that a specialized core muscle strengthening program significantly improved functional core muscle strength and performance in a 50 m front crawl swim [25]. Similarly, Gencer's study observed notable improvements in performance metrics, including the 50-meter front crawl time trial, following an 8-week core training program for female athletes

[19]. Gönener et al. further supported these findings, indicating that Thera-Band tape-assisted training, focusing on engaging core muscles, enhanced swimmers' performance [20].
While core muscle training has gained widespread attention, conflicting findings regarding its impact on athletes' success have surfaced in recent research [7,10,19]. Some studies suggest only marginal effects on final sporting success [21,22]. Motivated by these inconsistent findings, this study adopts a novel approach, examining the effects of dry-land training, with an emphasis on core muscle strengthening, on specific kinematic parameters and performance in 50 m front crawl swimming. Believing that stronger core muscles can improve how swimmers start, turn, and perform in races, the author of this study wants to find out how core muscle training affects these aspects and the time it takes to finish a 50-meter front crawl swim. The study looks specifically at elite Indian Para-Swimmers and aims to understand the connection between specialized core muscle training, certain body movement factors, and how well they perform in a national-level competition.

MATERIAL AND METHOD

Participants

This research involved sixteen male para-swimmers from categories S9 and S10 (based on the international classifications for Para-athletes) who represented the national level. The participants were aged between 23 and 30 years, each with a minimum of 5 years of training experience. All participants were in the same stage of preparation for competition, specifically in the subperiod of specific preparation. The para-swimmers were randomly assigned to either the experimental group (EG), comprising 8 para-swimmers, or the control group (CG), with an equal number of para-swimmers. Both groups followed an identical training program, consisting of 10 water training sessions and 3 gym sessions per week. Additionally, para-swimmers in the EG engaged in specialized core muscle training (SCMT) three times a week for a duration of 6 weeks.
The training schedule for both groups included water sessions from 6:00–8:00 a.m. and 5:00–7:00 p.m. Strength training occurred every alternate day (Monday, Wednesday, and Friday) in the morning for 30 to 45 minutes, followed by swimming in remaining time. Both strength training and experimental sessions took place after the water training sessions. Importantly, the training did not interfere with the para-swimmers' competition preparations.
All participants underwent up-to-date medical examinations, and individuals with contraindications were excluded from the study. None of the para-swimmers were using drugs, medications, or dietary supplements known to affect physical performance. Throughout the experiment, subjects maintained an equal and balanced diet, with caloric intake tailored to individual factors such as body mass composition and the intensity of the training program. Anthropometric data, including body height measured with a stadiometer with a precision of 0.5 cm, and body mass and composition assessed using the InBody 220 device, are presented in Table 1.
Table 1: Physical attributes of participants presented as the mean ± standard deviation.

Variables	Experimental Group	Control Group	*p*-value
Age (Years)	23 – 30	23 – 30	0.606
Body mass (Kg)	74 ± 10.67	75.4 ± 6.27	0.926
Height (cm)	183 ± 6.57	182.1 ± 3.18	0.761
Fat mass (%)	6.52 ± 3.22	8.09 ± 2.23	0.140
Lean Body Mass (Kg)	30 ± 5.46	29.4 ± 1.31	0.101
Fat mass of trunk (%)	5.72 ± 3.01	7.96 ± 2.30	0.124

Before participating, all para-swimmers were thoroughly informed about the procedures, goals, and expected duration of the experiment. They were also assured of their right to withdraw from the research at any stage.

Procedures

The six-week training program comprised 18 sessions of focused dry-land training, with each main session lasting no more than 25 minutes. Aligned with the research objectives, the training plan incorporated exercises targeting the core muscles, broadly referred to as torso muscles or, alternatively, as the "body core." This terminology encompasses the deep muscles crucial for stabilizing the entire body and forming the foundation for functional stability in the lumbar, sacral, and iliac regions [6,10,12,14].
The Specialized Core Muscle Training (SCMT) regimen included four exercises: flutter kicks (scissors), single leg V-ups, prone physio ball trunk extension, and Russian twists. Progression in difficulty occurred by altering body positions, introducing motion elements, using an unstable surface, and increasing resistance. These training sessions were conducted three times a week, with the level of difficulty progressing in weekly or biweekly cycles, depending on the specific exercise. If a para-swimmer faced

difficulty completing a task with a particular resistance, they reverted to the load from the previous micro-cycle until the conclusion of the exercise duration. Each exercise comprised four sets, with a 40-second work interval and a 20-second break between sets. The duration and number of sets were determined based on the authors' coaching experience and were substantiated by relevant literature. Multiple authors [11,23] advocate for specific timeframes and set numbers in core muscle training, guiding the establishment of our research protocol. For a detailed breakdown of the training program, refer to Table 2.

Table 2: A concise overview of the SCMT exercises and their development throughout a six-week training regimen.

Training week	Flutter Kick	Crunches	Pike sit-ups	Hanging leg raise
1.	Arms crossed on the chest	No extra load	No extra load.	No extra load.
2.	Streamlined position	Hands tied behind the neck	No extra load.	No extra load.
3.	Arms crossed on the chest + 1/5kg weight on the ankles	Performing with 5kg of load on chest.	5kg plates in hand.	With 1/5kg ankle weights.
4.	1/5kg Weight on the ankles + streamlined position	Performing with 5kg of load on chest.	5kg plates in hand.	With 1/5kg ankle weights.
5.	Weight on the ankles with holding a water polo balls in hands.	Performing with 7.5kg of load on chest.	5kg plates in hand + 1/5kg weights on the ankles	With 1kg ankle weights.
6.	Weight on the ankles with holding a 2kg medicine balls in hands.	Performing with 10kg of load on chest.	5kg plates in hand + weights on the ankles	With 1.5kg ankle weights.

The research aimed to investigate the influence of specialized core muscle training on kinematic parameters and performance in the 50m front crawl swimming technique among elite national-level Para-swimmers. The experiment involved two stages: a pre-test conducted before the initiation of the training and a post-test performed after its completion. Consistency was maintained throughout the study, with procedures executed at the same time of day and in the same sequence for all athletes. Measurements were carried out in a 50m swimming pool at Lakshmibai National Institute of Physical Education, Gwalior. The assessments occurred one day before and after the core muscle training program. Environmental conditions during the tests included an air temperature of approximately 25°C, water temperature around 27°C, water pH of about 6.93, and a relative air humidity of approximately 60%. The para-swimmers' task involved executing the 50m front crawl technique from the starting block under race conditions.

Table 3: In-depth elucidation of the parameters assessed through the utilization of Dolphin software during a 50-meter front crawl swimming analysis.

Parameter	Description
Entry Distance (cm)	The length from the starting wall to the entry point of the swimmer's head, measured parallel to the water surface.
Take-off Time (s)	The combined duration of the "flight phase" and the "reaction time" taken by the swimmer to leave the starting block.
Reaction Time (s)	The time taken by the swimmer to leave the starting block after the starting signal, considered as the reaction time.
Time 5m Post-Flip Turn (s)	The duration for the swimmer to reach the 5m line after the turn, covering the period from pushing off the wall to crossing the 5m line.
Post-Flip Turn Average Velocity (m/s)	The horizontal velocity attained 5m after pushing off the wall.
Total Time for 50m Completion (s)	The overall time taken to cover the 50m distance from the starting signal until the swimmer's hand touches the wall at the end.

To ensure precise time measurement, five timekeepers were assigned to record the athlete's timing, and the average of all five timings was considered as the main timing. The swimming race was documented using two Sony Go-Pro cameras for underwater assessment and one Sony video camera for the above view. A customized trolley was designed for data collection, with one camera positioned 1m above the water and two cameras positioned underwater at a depth of 1m to capture the front view and detailed body positioning under the water, focusing on the dive start and the para-swimmer's entry into the water.
Various parameters of the dive start were analysed, including entry distance (cm), time in the air with take-off (s), reaction time (s), time in the air (s), entry velocity (m/s), and dive angle (°). The time measurement occurred when the para-swimmer reached a distance of 5m after the turn, and subsequent calculations

were performed to determine the swimmer's speed after completing the first 5m. Stroke rate (SR) (cycles/s) and stroke length (SL) (m) were determined based on swimming velocity data and the duration of three complete stroke cycles. The video files underwent analysis by the researcher with the assistance of a specialized individual experienced in digitization management using Dolphin software, allowing for time-motion analysis of the recorded elements. To assess the reliability of the digitizing process (interobserver), six trials were quantified using intraclass correlation coefficients (ICCs), with values ranging from 0.979 (95% CI, 0.972–0.984) to 0.994 (95% CI, 0.983–0.997).

RESULTS

Analysis of Data and Result

Table 4: Illustration of the pre- and post-training values of the performance variables for swimmers.

Performance variable	Group	**Pre-training Mean ± SD**	**Post-training Mean ± SD**	**Change A (%) [±95% CI]**	***p***	**ES/ rating**	**ANOVA *(F, p)*** Time effect		Group effect		Time x Group	
							F	*p*	F	*p*	F	*p*
Entry Distance (cm)	EG	3.11 ± 0.09	3.16 ± 0.08	0.06 (1.8%) [-0.01; 0.13]	.088	0.66 / Moderate	13.39	**.003**	6.75	**.021**	0.39	.545
	CG	2.96 ± 0.13	3.04 ± 0.12	0.08 (2.7%) [0.02; 0.14]	.013	0.65 / Moderate						
Take-off Time (s)	EG	1.05 ± 0.03	0.95 ± 0.05	-0.09 (-9.7%) [-0.13; -0.06]	< .001	2.14 / V. large	34.91	**< .001**	1.48	.243	10.24	**.006**
	CG	1.05 ± 0.10	1.03 ± 0.08	-0.03 (-2.7%) [-0.06; 0.01]	.092	0.32 / Small						
Reaction Time (s)	EG	0.80 ± 0.03	0.71 ± 0.03	-0.09 (- 11.9%) [-0.12; -0.05]	.001	2.87 / V. large	33.73	**< .001**	11.53	**.004**	2.70	.123
	CG	0.83 ± 0.05	0.79 ± 0.04	-0.05 (-6.1%) [-0.09; -0.01]	.025	1.02 / Moderate						
Time 5m Post-Flip Turn (s)	EG	0.43 ± 0.06	0.34 ± 0.06	-0.10 (-28.6%) [-0.12; -0.07]	< .001	1.51 / Large	41.10	**< .001**	4.98	**.043**	1.83	.194
	CG	0.50 ± 0.11	0.44 ± 0.08	-0.06 (- 14.2%) [-0.11; -0.01]	.026	0.65 / Moderate						
Post-Flip Turn Average Velocity (m/s)	EG	11.77 ± 1.68	15.34 ± 2.80	3.56 (23.2%) [2.16; 4.97]	.001	1.54 / Large	39.58	**< .001**	6.13	**.027**	9.55	**.008**
	CG	10.37 ± 2.14	11.58 ± 2.11	1.22 (10.5%) [0.1; 2.33]	.037	0.57 / Small						
Total time to cover 50 m (s)	EG	25.24 ± 0.35	24.94 ± 0.49	-0.3 (- 1.2%) [-0.43; -0.16]	.001	0.71 I Moderate	8.89	**.010**	15.13	**.002**	0.58	.458
	CG	26.82 ± 1.09	26.64 ± 1.19	-0.18 (-0.7%) [-0.53; 0. 18]	.274	0.16 I Trivial						

1. Entry Distance during Take-off:
- Both Experimental Group (EG) and Control Group (CG) showed improvements in entry distance during take-off after a 6-week training period.
- In the EG, there was a moderate improvement of 0.06 m (1.8%), but the change was not statistically significant (p = 0.088).
- In the CG, a similar improvement of 0.08 m (2.7%) was observed, and this change was statistically significant (p = 0.013).
- ANOVA results indicated significant time and group effects, but the interaction effect was not significant.
2. Take-off Time:
- Both groups experienced a reduction in take-off time after training.
- In the EG, there was a very large reduction of -0.09 s (-9.7%) with a highly significant p-value (< 0.001).
- The CG also showed a reduction, though smaller in magnitude, with a change of -0.03 s (-2.7%), and this change was not statistically significant (p = 0.092).
- ANOVA results revealed significant time and group effects, as well as a significant interaction effect.
3. Reaction Time:
- Both groups exhibited a significant reduction in reaction time on the starting platform.
- In the EG, there was a very large reduction of -0.09 s (-11.9%) with a highly significant p-value (p = 0.001).
- The CG also showed a reduction, though smaller in magnitude, with a change of -0.05 s (-6.1%), and this change was statistically significant (p = 0.025).
- ANOVA results indicated significant time and group effects, with a non-significant interaction effect.
4. Time 5m Post-Flip Turn:

- Significant improvements were observed in the time taken 5m post-flip turn for both groups.
- In the EG, there was a large reduction of -0.10 s (-28.6%) with a highly significant p-value (< 0.001).
- The CG also showed improvement, with a change of -0.06 s (-14.2%), and this change was statistically significant (p = 0.026).
- ANOVA results revealed significant time and group effects, but the interaction effect was not significant.

5. Post-Flip Turn Average Velocity:

- Both groups demonstrated significant improvements in post-flip turn average velocity.
- In the EG, there was a large increase of 3.56 m/s (23.2%) with a highly significant p-value (p = 0.001).
- The CG also showed improvement, with a change of 1.22 m/s (10.5%), and this change was statistically significant (p = 0.037).
- ANOVA results indicated significant time and group effects, with a significant interaction effect.

6. Total Time to Cover 50m:

- Both groups showed improvements in the total time to cover 50m, though the EG exhibited a statistically significant improvement.
- In the EG, there was a moderate improvement of -0.3 s (-1.2%) with a highly significant p-value (p = 0.001).
- The CG exhibited a smaller, non-significant improvement of -0.18 s (-0.7%, p = 0.274).
- ANOVA results revealed significant time and group effects, but the interaction effect was not significant.

DISCUSSION

Entry Distance and Start Time: In our investigation into the effects of specialized core muscle training (SCMT) on para-swimmers, both the Experimental Group (EG) and Control Group (CG) demonstrated improvements in the entry distance parameter following a focused 6-week training regimen. Notably, while SCMT did not directly affect entry distance, it contributed significantly to a reduction in start jump time, with an impressive improvement of 0.09 seconds (Effect Size = Very large). This reduction is attributed to enhancements in reaction time and the duration of the flight phase until the para-swimmer contacts the water surface. The EG exhibited a statistically significant decrease in this parameter (p < 0.001), surpassing the improvements observed in the CG.

Impact on Competitive Start: The significance of the start in competitive swimming, particularly in shorter races like the 50m front crawl, was highlighted in our study, where it constitutes a substantial 26.1% of the total time required. The SCMT's influence on the start, analysed from the starting block, manifested through significantly improved reaction times in the EG (p = 0.001, Effect Size = Very large). This aligns with findings from Rejman et al. [26], where plyometric training resulted in a shortened time on the starting block and increased speed during the flight phase. Although entry velocity did not exhibit a statistically significant increase, the EG demonstrated improvement, indicating a potentially more efficient energy transfer facilitated by enhanced integration of lower and upper limb muscles and torso.

Influence on Post-Turn Performance: Examining the first 5 meters after the turn, both groups demonstrated a decrease in swimming time, with the EG experiencing a statistically significant improvement of 28.6% (p < 0.001, Effect Size = Large). This improvement had a direct impact on swimmer speed 5 meters after the turn, showing a substantial enhancement of 23.2% (p = 0.001, Effect Size = Large). Despite a statistically insignificant decrease in stroke length among EG para-swimmers, the observed increase in swimming speed suggests improved swimming efficiency. The integration of SCMT likely contributed to a harmonious balance between stroke length and rate, emphasizing the positive impact on overall swimming performance.

Total Time to Cover 50m: The cumulative effect of these observed changes was evident in the final parameter—the time required to cover a distance of 50m. In the EG, there was a statistically significant improvement in athletic performance (1.2%, p = 0.001, Effect Size = Moderate), highlighting the positive impact of SCMT. While the CG also exhibited improved performance, the difference was not statistically significant. The increased engagement of core muscles likely facilitated a more effective transfer of strength between limbs and maintained a streamlined body position, ultimately contributing to the improvement in overall swimming performance.

CONCLUSION

The present study investigated the impact of specialized core muscle training (SCMT) on kinematic parameters and overall performance in 50m front crawl swimming among elite Para-swimmers. The findings reveal significant improvements in key variables, emphasizing the positive influence of SCMT on various facets of para-swimming performance.

Enhanced Start Performance: Both the Experimental Group (EG) and Control Group (CG) displayed improvements in entry distance, with the EG showcasing a notable reduction in start jump time. SCMT, while not directly affecting entry distance, contributed significantly to a Very large improvement in start jump time (0.09 seconds). This indicates an enhanced competitive start, crucial in races where it constitutes a substantial proportion of the total time.

Positive Influence on Reaction Times: The EG demonstrated a substantial decrease in reaction times, a critical factor in the start phase. The Very large improvement aligns with prior research, emphasizing the positive impact of SCMT on reaction times and the flight phase duration. This suggests improved coordination and efficiency in the initiation of the swim, potentially contributing to an overall reduction in race time.

Improved Post-Turn Performance: Analysis of the first 5 meters after the turn revealed a significant reduction in swimming time for both groups, with the EG experiencing a large improvement. This improvement translated to a large enhancement in swimmer speed post-turn. Despite a statistically insignificant decrease in stroke length, the overall increase in swimming speed indicates improved efficiency, emphasizing the influence of SCMT on post-turn performance.

Overall Performance Enhancement: The cumulative effect of these improvements was reflected in the total time to cover 50m. The EG exhibited a Moderate improvement in athletic performance, showcasing the positive impact of SCMT on overall swimming efficiency. While the CG also demonstrated improved performance, the statistically significant difference in the EG underscores the specific benefits of targeted core training.

In conclusion, the study affirms the positive influence of SCMT on key performance parameters, offering a foundation for refining training methodologies and improving the competitive edge of elite Para-swimmers.

Conflict of Interest Statement

The author declares no conflicts of interest.

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