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# Impact of Individual-Specific Strength Exercises on Knee Muscle Strength and Speed Performance in Speed Skaters: A Randomised Control Trial

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**Abstract.** Background: Speed skating performance relies heavily on lower limb strength, neuromuscular control, and coordination. Weakness of knee muscles can limit performance and increase the risk of overuse injuries. Individual-specific strengthening of knee flexors and extensors may enhance strength and skating speed, yet evidence in young skaters is limited. Objective: To evaluate the effect of individualized knee muscle strengthening on knee flexor and extensor strength and speed performance in young speed skaters. Methods: Sixty skaters aged 8–14 years were randomly assigned to an experimental group (individual-specific strengthening, 8 weeks, 3 sessions/week) or a control group (routine skating only). Training loads were based on 1-RM values and progressed using a pyramidal model (80–95% 1-RM). Knee strength was measured using the Modified Sphygmomanometer Strength Test (MSST), and skating performance using the Inline Skating Skill Test (ISST). Data were analysed using paired and unpaired t-tests ($p < 0.05$). Results: The experimental group showed significant increases in knee flexor ($51.06 \pm 7.8 \rightarrow 57.73 \pm 7.4$ mm Hg) and extensor strength ($60.0 \pm 8.3 \rightarrow 66.2 \pm 7.6$ mm Hg) ($p < 0.001$), along with improved Inline Skating Skill Test (ISST) performance time ($27.62 \pm 2.7 \rightarrow 24.34 \pm 2.5$ s, $p < 0.001$). No significant changes were observed in the control group. Conclusion: Individual-specific strengthening produced meaningful improvements in knee muscle strength and skating speed in young speed skaters. Incorporating such targeted resistance training into routine practice may enhance performance and reduce injury risk.

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# 1. Introduction

Talent development programs in sports aim to identify and nurture young athletes with the potential to achieve elite performance levels. Reaching such performance requires not only technical mastery but also exceptional physical capacity [1].

Speed skating is a time-trial discipline in which an athlete's performance is evaluated based on the duration required to traverse a prescribed distance. The sport demands strong coordination, endurance, and lower limb muscle strength, particularly around the knee joint. Inline speed skating, increasingly popular among youth athletes, has also been associated with a high incidence of knee injuries due to repetitive loading and inadequate muscular balance. [2,3].

The quadriceps and hamstrings are critical in generating propulsion, maintaining posture, and absorbing impact forces during skating. The balance between these muscles, commonly expressed as the hamstring-to-quadriceps (H:Q) ratio, influences joint stability and risk of injury [4,5]. Physiotherapeutic strength programs tailored to individual muscle needs can correct imbalances and enhance functional performance.

Muscle force generation is determined by motor-unit recruitment, cross-bridge formation, and neural activation [6]. Progressive resistance training enhances these factors, improving dynamic stability and neuromuscular coordination [7]. The Modified Sphygmomanometer Strength Test (MSST) provides a reliable and accessible measure of isometric muscle strength [5], while the Inline Skating Skill Test (ISST) evaluates both technique and speed under performance conditions [9].

Considering the scarcity of evidence on tailored strength-training approaches for youth skaters, this study intended to examine the impact of individualized knee muscle–strengthening programs on knee flexor and extensor strength as well as speed performance, utilizing standardized clinical and performance evaluation methods.

# 2. Materials and Methodology

This study followed a randomized controlled trial design conducted over a period of four months. The research was carried out at the On-field Indoor Stadium and Saint Mary's School, Rajkot, involving competitive speed skaters who met the predefined inclusion criteria. A purposive sampling technique was used to recruit participants, with a total of 60 skaters enrolled. Participants were randomly allocated into two groups—experimental and control—using a computer-generated sequential method. The study utilized a single-blind design wherein participants remained unaware of their assigned group.

Ethical clearance for the investigation was granted by the Institutional Ethics Committee (Registration No. ECR/259/Indt/GJ/2016), and the trial was prospectively registered with the Clinical Trials Registry of India (CTRI/2019/09/021146). All participants, along with their guardians, received detailed information regarding the study procedures, and written informed consent was obtained before enrollment.

## 2.1 Participants and Selection Criteria

Participants included male and female speed skaters aged 8–14 years with a minimum of two years of professional skating experience**.** Skaters who were uncooperative, had recent musculoskeletal injuries, or were engaged in activities other than roller speed skating were excluded from the study. The selected participants represented an active and trained youth athlete population suitable for the study's objectives.

## 2.2 Intervention and Procedure

After recruitment, baseline outcome measures were recorded for both groups. The experimental group underwent an eight-week, individual-specific knee muscle strengthening program**,** while the control group continued with regular practice under coach supervision. Both groups trained three times weekly prior to intervention.

The one-repetition maximum (1-RM) test was conducted for all participants to determine their individualized training loads. The 1-RM test was performed to establish maximal voluntary contraction capacity for lower limb exercises. An initial load equivalent to 40% of body weight was used for quadriceps-related movements and 60% of body weight for hamstring-related movements. Each participant performed concentric contractions with brief rest intervals of one minute between trials. The heaviest load successfully lifted once was recorded as the 1-RM value for that exercise [4].

To facilitate individualized resistance training, a modified sandbag was designed with adjustable load capacity ranging from 0.5 kg to 4 kg**.** The sandbag contained four internal pockets—three holding 1 kg sand packets and one containing two 0.5 kg packets. This design allowed easy load adjustment by adding or removing packets as required during progressive training sessions.


**Fig 1.** Modified adjustable sandbag designed for individualized strength training.

The training program followed a pyramidal loading method, in which repetitions decreased as load intensity increased. The regimen comprised seven lower limb exercises as shown in

Fig 2.: (1) standing leg abduction, (2) standing calf raises, (3) single-leg extension, (4) standing single-leg curl, (5) seated single-leg press, (6) seated single leg curl, and (7) standing leg adduction. Each exercise was performed in four sets at 80–95% of 1-RM**,** with progressive overload. Proper technique was demonstrated and supervised throughout the program.


**Fig 2.** Individual Specific Training Regimen.

**Table 1.** Interventional protocol for experimental group [pyramidal training model]. The table summarizes weekly progressions number of sets, repetitions, and load intensity.

| Movement | Days/ Week | Number of Sets | Number of Repetition | Load(% Of 1-RM) | Resting |
|---|---|---|---|---|---|
| 1<br>2<br>3<br>4<br>5<br>6<br>7 | 3 | 4 | 8 | 85 | 30 |
| | | | 6 | 90 | |
| | | | 4 | 95 | |
| | | | 2 | 80 | |

The data collection procedure is illustrated in Fig. 3, summarizing participant enrollment, randomization, group allocation, intervention flow, and post-intervention outcomes. Baseline outcome measures were recorded on day one, and post-intervention assessments were conducted after completion of the eight-week program.

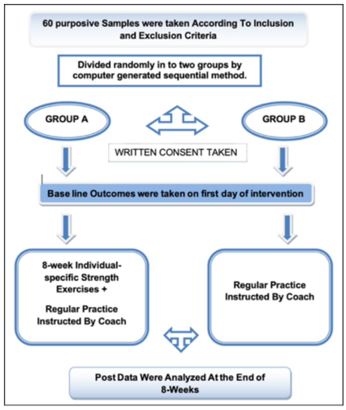


**Fig 3.** Flowchart of study methodology showing participant selection, randomization, and intervention process.

## 2.3 Outcome Measures

### *2.3.1 Inline Skating Skill Test (ISST)*

Performance was assessed using the Inline Skating Skill Test**,** a validated measure of skating performance [21]. The test involved an 83-meter course incorporating sport-specific tasks such as start acceleration, 360° circling, S-turns, push-offs, and direction changes. The aim was to complete the course as fast as possible while maintaining technical accuracy.

Two circular markers were placed 4 m apart, followed by three acceleration runs leading into slalom sections. Cones in the wide slalom section were spaced 4 m apart with alternating 1.4 m deviations, while the narrow slalom section maintained the same 4 m spacing but smaller [0.3 m] deviations. Performance time from initiation to completion was measured to the nearest 0.01 s using a calibrated electronic timing system. Participants were instructed to skate around all cones with full wheel contact on the surface; any deviation required a retest after adequate rest. Two trained examiners supervised all tests to ensure procedural uniformity.

**Fig 4.** Layout of the Inline Skating Skill Test course used for performance evaluation.

### *2.3.2 Modified Sphygmomanometer Strength Test (MSST)*

Knee flexor and extensor strength was assessed using the Modified Sphygmomanometer Strength Test (MSST), a reliable method for measuring static muscle strength [7]. A standard sphygmomanometer (0–30 mm Hg range) was adapted for the test. The cuff was inflated to 100 mm Hg to remove air folds, then reduced to 20 mm Hg and sealed, allowing a working range of 20–30 mm Hg. The device was positioned parallel to the limb segment, and the force exerted during maximal contraction was recorded from the manometer reading.

A Mulligan belt made of inelastic material was used to stabilize the limb, minimizing examiner-dependent variation. Testing positions are summarized in Table 2.

**Table 2.** Testing positions for Modified Sphygmomanometer Strength Test (MSST).

| Muscle Group | Position | Description |
|---|---|---|
| Knee Flexors | Sitting | Trunk upright, arms crossed, hip and knee flexed to 90°, feet unsupported |
| Knee Extensors | Sitting | Trunk upright, arms crossed, hip and knee flexed to 90°, feet unsupported |

Strength testing was conducted by two trained evaluators. The dominant limb was defined as the leg used to kick a ball. The order of testing was randomized to avoid fatigue bias. A third examiner, blinded to allocation, recorded readings to ensure objectivity. Participants were verbally encouraged during each 5-second maximal effort (“one, two, three, go, strength, strength, relax”) to achieve peak contraction. Familiarization trials were conducted before testing, and one-minute rest intervals were provided between attempts. Examiners cautioned participants against performing the Valsalva maneuver. Both muscle groups were assessed before and after the intervention period for all participants.

# 3. Results

A total of 60 participants were included in this randomized controlled trial, with 30 skaters each in the experimental and control groups. Data were analyzed for demographic variables [age and gender] and outcome measures including knee flexor and extensor muscle strength [assessed by the Modified Sphygmomanometer Strength Test] and skating performance [assessed by the Inline Skating Skill Test]. Statistical analysis was conducted using paired and unpaired *t*-tests to compare intra-group and inter-group differences. A *p*-value of less than 0.05 was considered statistically significant.

## 3.1 Participant Demographics

### *3.1.1 Age Distribution*

**Table 3.** Age distribution of study participants.

| Group | Mean Age (years) |
|---|---|
| Control | 9.63 |
| Experimental | 9.80 |

The mean age of participants in the control group was 9.63 years, while that of the experimental group was 9.80 years**,** indicating homogeneity across groups.

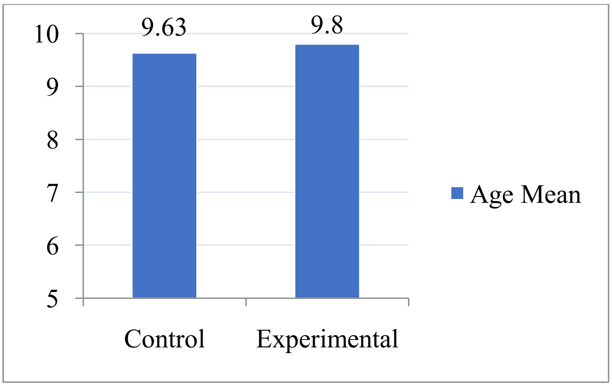


**Fig 5.** Mean age distribution of participants in control and experimental groups.

**Interpretation:** Both groups were age-matched, minimizing age-related influence on strength or performance outcomes.

### *3.1.2 Gender Distribution*

**Table 4.** Gender distribution among participants.

| Group | Total Participants | Male | Female |
|---|---|---|---|
| Control | 30 | 26 [87%] | 4 [13%] |
| Experimental | 30 | 26 [87%] | 4 [13%] |

**Interpretation:** The gender ratio was uniform across both groups, supporting comparability in muscular and performance parameters.

## 3.2 Intra-group Analysis

### *3.2.1 Control Group*

**Table 5.** Intra-group analysis of knee flexor strength for control group.

| Side | Pre-test Mean ± SD (mm Hg) | Post-test Mean ± SD (mm Hg) | *t*-Value | *p*-Value |
|---|---|---|---|---|
| Right | 50.2 ± 7.5 | 51.4 ± 8.22 | 3.22 | 0.003 |
| Left | 49.3 ± 7.6 | 50.2 ± 7.7 | 2.09 | 0.450 |

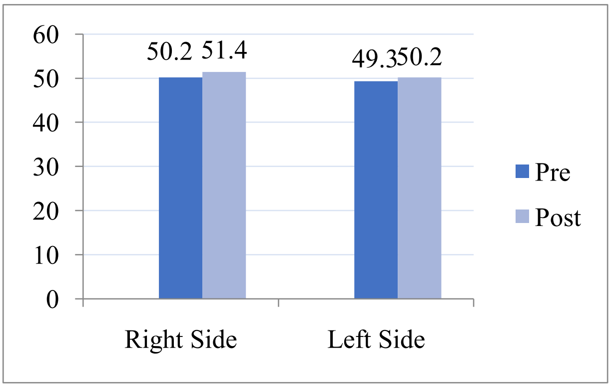


**Figure 6.** Pre- and post-intervention comparison of knee flexor strength in the control group.

**Interpretation:** The control group demonstrated a non-significant improvement in knee flexor strength following the regular skating practice program.

**Table 6.** Intra-group analysis of knee extensor strength for control group.

| Side | Pre-test Mean ± SD (mm Hg) | Post-test Mean ± SD (mm Hg) | *t*-Value | *p*-Value |
|---|---|---|---|---|
| Right | 61.2 ± 8.2 | 60.8 ± 7.8 | 0.817 | 0.420 |
| Left | 59.8 ± 8.1 | 60.2 ± 8.1 | 1.12 | 0.269 |

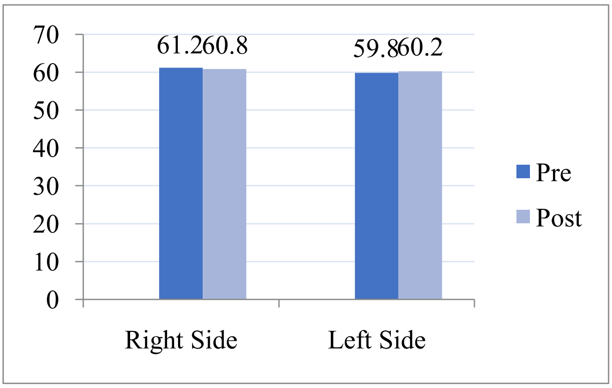


**Fig 7.** Intra-group analysis of knee extensor strength for control group.

**Interpretation:** No statistically significant improvements were observed in either limb, indicating that regular skating alone did not enhance extensor strength.

**Table 7.** Intra-group analysis of Inline Skating Skill Test for control group.

| Measure | Pre-test Mean ± SD | Post-test Mean ± SD | *t*-Value | *p*-Value |
|---|---|---|---|---|
| ISST Time (Seconds) | 29.2 ± 2.63 | 29.0 ± 2.74 | 0.959 | 0.345 |

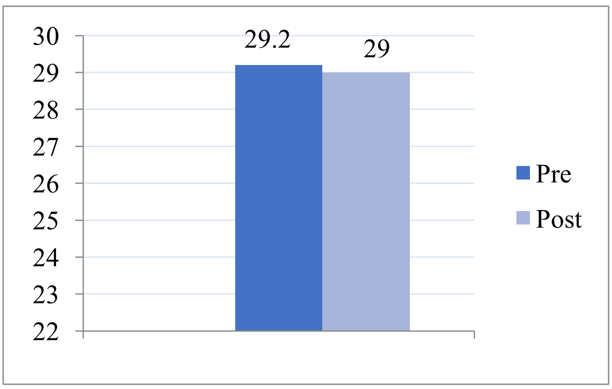

**Fig 8**. Intra-group analysis of Inline Skating Skill Test for control group.

**Interpretation:** Regular skating practice alone did not produce a significant improvement in skating performance.

### *3.2.2 Experimental Group*

**Table 8.** Intra-group analysis of knee flexor strength for experimental group.

| **Side** | **Pre-test Mean ± SD (mm Hg)** | **Post-test Mean ± SD (mm Hg)** | ***t*-Value** | ***p*-Value** |
|---|---|---|---|---|
| Right | 51.06 ± 7.8 | 57.73 ± 7.4 | 16.6 | 0.000 |
| Left | 50.0 ± 7.5 | 57.26 ± 7.2 | 16.1 | 0.000 |

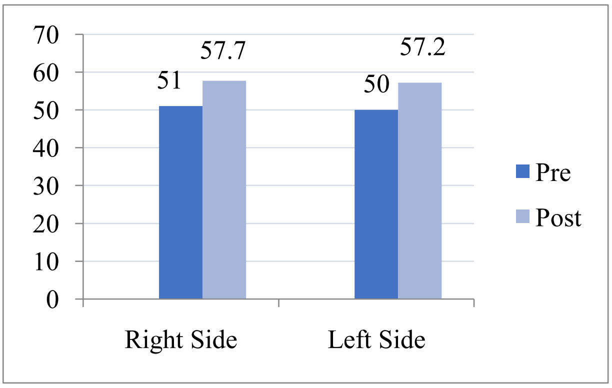


**Fig. 9** Pre- and post-intervention comparison of knee flexor strength in experimental group.

**Interpretation:** Statistically significant gains were noted bilaterally, confirming the effectiveness of the strength program in improving knee flexor muscle strength.

**Table 9.** Intra-group analysis of knee extensor strength for experimental group.

| **Side** | **Pre-test Mean ± SD (mm Hg)** | **Post-test Mean ± SD (mm Hg)** | ***t*-Value** | ***p*-Value** |
|---|---|---|---|---|
| Right | 60.0 ± 8.3 | 66.2 ± 7.6 | 15.97 | 0.000 |
| Left | 59.2 ± 7.9 | 65.4 ± 7.8 | 13.10 | 0.000 |

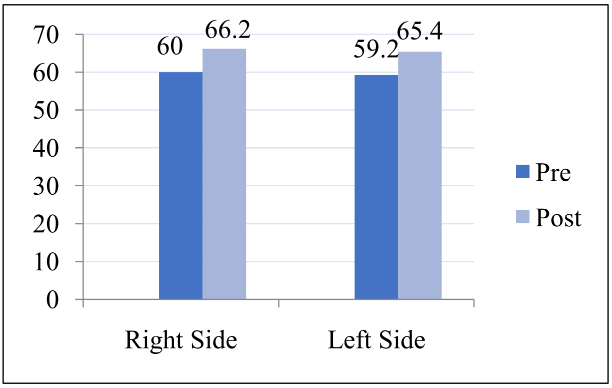


**Fig 10.** Intra-group analysis of knee extensor strength for experimental group.

**Interpretation:** Both limbs exhibited significant improvements, highlighting the positive influence of targeted knee muscle strengthening exercises.

**Table 10.** Intra-group analysis of Inline Skating Skill Test for experimental group.

| Measure | Pre-test Mean ± SD | Post-test Mean ± SD | *t*-Value | *p*-Value |
|---|---|---|---|---|
| ISST Time (Seconds) | 27.62 ± 2.7 | 24.34 ± 2.51 | 22.92 | 0.000 |

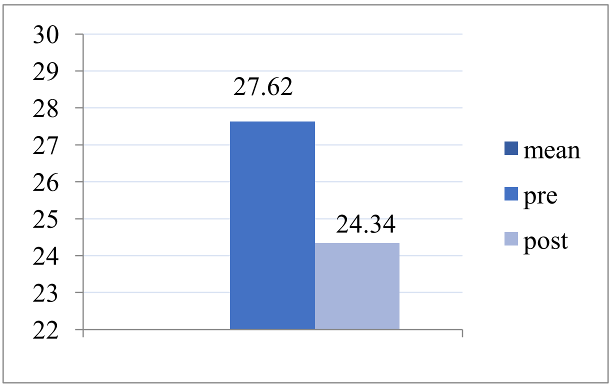


**Fig 11.** Intra-group analysis of the Inline Skating Skill Test for the experimental group.

**Interpretation:** The individualized exercise protocol produced a statistically significant improvement in skating speed and coordination.

*3.2.3 Inter-group Analysis*

Between-group comparisons revealed significant post-intervention differences in all parameters, favoring the experimental group.

**Table 11.** Inter-group comparison of knee flexor strength [post-test values].

| Side | Control Mean ± SD (mm Hg) | Experimental Mean ± SD (mm Hg) | *t*-Value | *p*-Value |
|---|---|---|---|---|
| Right | 51.4 ± 1.91 | 57.73 ± 2.17 | 9.948 | 0.000 |
| Left | 50.2 ± 2.2 | 57.26 ± 2.5 | 10.16 | 0.000 |

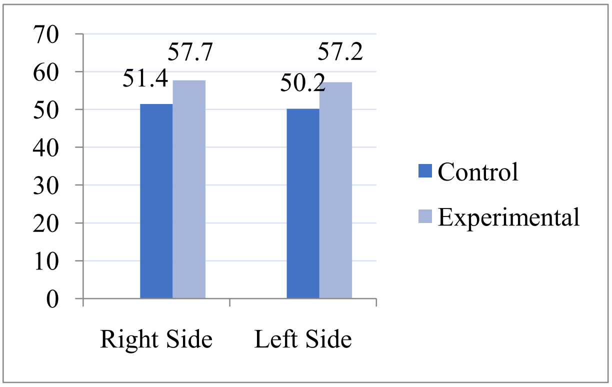


**Fig 12.** Inter-group comparison of knee flexor strength [post-test values].

**Interpretation:** The experimental group exhibited significantly greater knee flexor strength, confirming the efficacy of the intervention.

**Table 12.** Inter-group comparison of knee extensor strength [post-test values].

| Side | Control Mean ± SD (mm Hg) | Experimental Mean ± SD (mm Hg) | *t*-Value | *p*-Value |
|---|---|---|---|---|
| Right | 60.8 ± 2.2 | 66.2 ± 2.17 | 11.99 | 0.000 |
| Left | 60.2 ± 2.2 | 65.4 ± 2.6 | 8.9 | 0.000 |

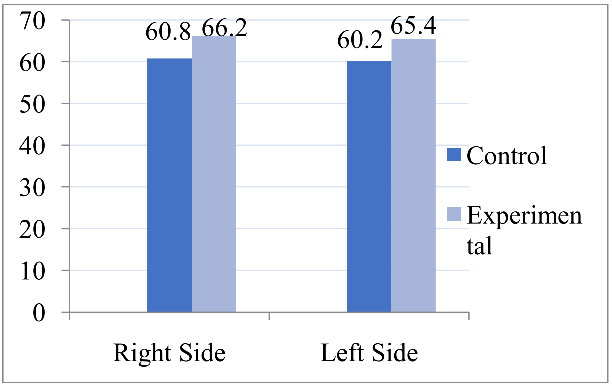

**Fig. 13.** Inter-group comparison of knee extensor strength [post-test values].

**Interpretation:** Significant differences between groups indicate superior gains in extensor muscle strength in the experimental group.

**Table 13.** Inter-group comparison of Inline Skating Skill Test [post-test values].

| Group | Mean ± SD (Seconds) | *t*-Value | *p*-Value |
|---|---|---|---|
| Control | 29.0 ± 0.98 | 13.43 | 0.000 |
| Experimental | 24.3 ± 0.77 | | |

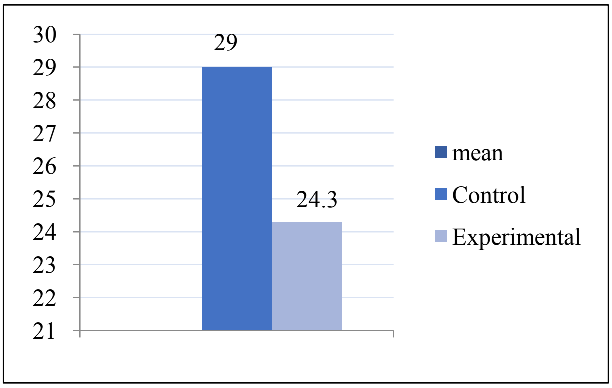


**Fig. 14.** Inter-group comparison of Inline Skating Skill Test [post-test values].

**Interpretation:** The substantial reduction in completion time among experimental participants confirms that individual-specific knee strengthening exercises significantly improved skating speed and technical performance compared to standard training.

# 4. Discussion

## 4.1 Overall Findings and Performance Improvements

The findings of this randomized controlled trial clearly demonstrate that individualized knee muscle strengthening substantially improves both muscle performance and skating speed in young speed skaters. Roller- and ice-skating exhibit similar biomechanical and physiological characteristics, with comparable demands on the lower limb joints and musculature, particularly around the hip and knee. This validates off-ice training as a highly specific and effective adjunct to maintain and enhance conditioning during non-competition phases [10]. The resemblance in push-off mechanics and joint kinetics between roller and ice skating suggests that strength adaptations developed through off-ice resistance training are transferable to on-ice performance.

### 4.2 Effects of Routine Training Versus Individualized Strengthening

In the present study, the control group, which continued routine skating practice without additional strengthening exercises, did not show any meaningful gains in either muscle strength or performance outcomes. This indicates that technical repetition alone is insufficient to produce substantial neuromuscular or morphological adaptation. Although skating inherently involves repetitive use of the lower limb, the stimulus may not be intense enough to induce hypertrophy or enhance motor-unit recruitment required for measurable strength gains. Similar findings were highlighted by Delecluse et al., who concluded that high-resistance training was superior to high-velocity training in enhancing sprint acceleration phases, implying that higher loading intensities are essential for improving power output and neuromuscular activation [11].

### 4.3 Neuromuscular Adaptations in the Experimental Group

The experimental group, which performed individual-specific strengthening exercises, exhibited a marked increase in both knee flexor and extensor strength, accompanied by significant improvement in ISST performance. This demonstrates a direct link between targeted muscle strengthening and enhanced skating speed. Improved muscle recruitment patterns, increased cross-sectional area of muscle fibers, and enhanced synchronization of agonist–antagonist activity likely contributed to the observed gains. These adaptations align with neuromuscular principles described by Enoka and Duchateau, emphasizing that improved rate coding and motor-unit firing frequency contribute to enhanced force production during sport-specific activities [6]. Likewise, Cronin and Sleivert supported that maximal power training influences neural drive and rate of force development, both critical for short-duration explosive movements such as skating sprints [7]. The progressive overload design of the intervention ensured gradual neuromuscular adaptation and reduced fatigue-related plateauing effects, allowing participants to sustain improvement throughout the 8-week period [12].

### 4.4 Importance of Hamstring-to-Quadriceps Ratio

A crucial factor in optimizing skating performance is the balance between quadriceps and hamstring strength, represented by the H:Q ratio. The hamstrings function as dynamic stabilizers during propulsion and deceleration phases, counteracting anterior tibial translation and reducing strain on the anterior cruciate ligament. Studies have demonstrated that an ideal H:Q ratio helps prevent overuse and acute knee injuries [4,5]. The present findings affirm that strengthening both muscle groups in a balanced, individualized manner enhances not only performance but also joint stability and injury prevention.

### 4.5 Biomechanical and Postural Considerations

The biomechanical harmony between hip and knee joints plays a decisive role in efficient skating movement. Khuyagbaatar et al. highlighted that optimal inter-joint coordination of the hip–knee complex contributes to effective power transmission during short-track skating, reducing compensatory movements and mechanical inefficiencies [3]. These findings are mirrored in the current study, where improved knee strength likely facilitated smoother, more synchronized lower limb movements, improving both propulsion and control. Additionally, better neuromuscular control may have reduced energy leaks across joints, enhancing overall skating economy and endurance.

From a postural and mechanical perspective, Konings et al. described that the crouched skating position, characterized by reduced knee and trunk angles, provides aerodynamic benefits but simultaneously increases muscular and metabolic stress [13]. Maintaining this posture efficiently requires high endurance of the knee extensor and flexor muscles. The present study's results indicate that improved muscle strength allows athletes to sustain biomechanically efficient postures for longer durations, minimizing fatigue-induced postural deterioration, which often leads to performance decline during longer events. Hence, targeted strengthening directly supports movement economy and fatigue resistance, crucial for competitive skating.

### 4.6 Clinical and Practical Implications

Furthermore, the design of the current strengthening program emphasized individual specificity, where training loads were derived from each participant's one-repetition maximum (1-RM) assessment. This personalized approach ensured optimal resistance intensity tailored to individual capacity and progression, aligning with established sports rehabilitation principles. Such a design not only enhanced muscle performance but also prevented overtraining and muscle imbalance. Incorporating clinically feasible tools like the Modified Sphygmomanometer Strength Test (MSST)and the Inline Skating Skill Test (ISST) provided reliable, accessible, and objective quantification of performance improvements making this model highly adaptable for routine physiotherapy and sports conditioning setups.

### 4.7 Summary and Recommendations

Overall, this study underscores that individual-specific physiotherapy-based resistance programs effectively complement traditional on-skate training by improving strength symmetry, joint stability, and neuromuscular coordination. The structured progression of resistance and the use of functional exercises contributed to substantial gains in both strength and speed. The ability to maintain a balanced H:Q ratio is of particular importance in young athletes, as asymmetries during growth phases can predispose to chronic knee issues. Consistent with Maly et al., who emphasized the impact of bilateral strength asymmetry on athletic performance and injury risk, the present findings reinforce the necessity of balanced, targeted strengthening [14].

Therefore, the outcomes of this trial strongly advocate for the inclusion of individual-specific, physiotherapy-supervised strengthening interventions within the regular training regimen of youth speed skaters. Such integration can lead to sustainable improvements in knee joint stability, muscular endurance, and overall performance potential, while minimizing the risk of injuries associated with repetitive high-intensity skating movements.

## 5. Conclusion

Individual-specific knee muscle strengthening exercises led to significant improvements in both knee flexor and extensor strength and speed performance in young speed skaters. Incorporating such tailored strength programs into regular training enhances performance, improves knee joint stability, and may reduce injury risk.

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