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ORIGINAL ARTICLE

Effects of Two Isometric Strength Training Methods on Jump and Sprint Performances: A Randomized Controlled Trial

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Abstract

Purpose Isometric strength training (IST) with rapid non-sustained contraction (RIST) is effective in improving the ability to generate force rapidly. However, the neuromuscular adaptation of IST with sustained contraction (SIST) and RIST is not known. Therefore, the aim of the study was to compare the neuromuscular adaptations of RIST with SIST.

Methods Thirty-three national floorball players (23.9 ± 3.1 years old; 1.69 ± 0.08 m; 64.6 ± 11.1 kg) were recruited for this study. Pre- and post-test included countermovement jump (CMJ), 30-m sprint (TT30), isometric squat at 90° (ISqT90) and 120° (ISqT120) knee angles. They were randomly assigned to either control (Con) ($n = 9$), RIST ($n = 12$) or SIST ($n = 12$) group and performed 12 sessions of intervention training. All groups performed the same sets of exercises, but RIST and SIST had to perform ISqT with and without sustained contraction, respectively.

Results Time × group effect for CMJ height ($P = 0.01$, $\eta_p^2 = 0.25$), peak force (PF) ($P = 0.03$, $\eta_p^2 = 0.22$) and rate of force development (RFD) ($P = 0.02$, $\eta_p^2 = 0.22$) obtained from ISqT120 were noted. A main effect for time was observed in CMJ height, PF obtained from ISqT90 and ISqT120, and RFD obtained from ISqT90 ($P < 0.01$, $0.27 < \eta_p^2 < 0.57$). There was greater improvement in TT30 ($P = 0.043$, $d = 3.00$), ISqT90 PF ($P = 0.034$, $d = 3.12$), ISqT120 PF ($P = 0.003$, $d = 4.54$) and ISqT120 RFD ($P = 0.033$, $d = 1.36$) in the SIST than the Con group.

Conclusion SIST was more effective in improving strength and dynamic performance as compared to RIST, making it a viable training method to enhance dynamic performances.

Keywords Countermovement jump · Isometric squat · Peak force · Rate of force development

Introduction

Isometric strength training (IST) is a mode of resistance training characterized by production of muscular force without any external movement. This mode of resistance training has various advantages over other dynamic mode, including lower energy demand and superior at increasing isometric strength and joint angle specific force production capability [21]. As upper and lower limb isometric strength, assessed using various isometric strength assessment, has been reported to have small to very large correlation with sports related dynamic movements ($r^2 = 0.12$–0.70) [22], it is possible that performing IST may enhance dynamic performances.

There are multiple studies on the effects of IST on maximum force development and dynamic exercise performance available in the literature [2–5, 7, 8, 13, 17, 18, 20, 24, 30]. Burke et al. [8] reported that performing maximal IST resulted in significantly increased maximum hip extensor force production in as short as 5 days. In addition, Folland et al. [13] reported that IST resulted in similar magnitude in the improvement of isokinetic knee extension after performing IST (10 × 2 s × 75% maximal contraction knee extension at four knee angles) when compared to variable resistance strength training. In contrast, Lee et al. [20] reported that the magnitude of improvement in isokinetic leg extension strength after performing IST (undergoing 10 × 1 s × 75%

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maximal contraction knee extension at four knee angles) was only half of that after performing isokinetic strength training. Although participants in both studies performed 10 repetitions of isometric contraction per session, the duration of the contraction in Folland et al. [13] 's protocol was double of that in Lee et al. [20] (2 s vs. 1 s). The sustained contraction protocol (i.e. maintaining isometric contraction for > 1 s) used by Folland et al. [13] could have resulted in relatively greater strength gain than the non-sustain contraction protocol by Lee et al. [20], as was reported in other studies [3, 30]. Nevertheless, the findings from the aforementioned studies indicated that IST is also an effective method for increasing muscular strength. However, the use of IST for the enhancement of dynamic performance requires further investigation.

Two studies using the same protocol have reported that rapid contraction IST without sustaining the isometric contraction elicited superior gains in the ability to generate force rapidly, as compared to IST that required participant to sustain isometric contraction [3, 30]. In these studies, one group had to perform rapid contraction isometric training (RIST); whereby, each repetition was executed as fast and as hard as possible to, between 80% and 90% maximum voluntary contraction (MVC) for ~ 1 s (i.e. no sustaining of isometric contraction). The other group, had to execute the isometric contraction gradually to 75% MVC and sustain for 3 s. In both studies, participants underwent a training volume of 4 sets of 10 repetitions in each session, but in one study participants attended 16 sessions [30] and in the other 36 sessions [3]. These two studies reported a superior improvement in force production at 50–100 ms after performing RIST. However, the group performed the sustain contraction had superior improvement in maximum force. Faster sprinters have been reported to produce higher isometric force at 50–100 ms as compared to slower sprinters, and isometric force at 150 ms was most strongly related to jump height [31]. Therefore, chronic adaptation to RIST has the possibility of improving performance in exercises that require rapid contraction of muscles. However, it is important to note that maximum strength plays an important role in generating greater muscular power and superior athletic performance [10]. Therefore, it is important to develop a training protocol that can enhance maximum and rapid force development simultaneously.

Altogether, it seems that a sustain contraction IST leads to superior maximum strength gain; while, RIST leads to superior gain in the ability to generate force rapidly [3, 30]. However, to the authors' knowledge, the neuromuscular effect of an IST method that requires rapid and sustained contraction (SIST) was never compared. Based on the findings of these two studies, it might be possible that SIST would result in similar improvements in maximum strength as a sustained contraction protocol, and similar improvement in the ability to generate force rapidly as the RIST protocol.

Despite the ability for IST to increase force production, there are also conflicting findings on the effects of IST on CMJ performance in the current literature. Some studies reported that IST did not result in improvement in CMJ height [3, 4, 17, 24]; while others reported that IST led to improvements [5, 7]. It was noted no improvements in jump performance in studies that either did not use multi-joint exercise, did not perform IST with rapid contraction, or did not perform IST at multiple joint angles [1]. Indeed, these factors were present in studies reporting significant improvements in CMJ height [5, 7]. Even though Bogdanis et al. [7] noted improvements in CMJ performance, participants in this study performed multi-joint IST exercise with rapid contraction and also vertical jumps during training. Thus, the effect of performing multi-joint IST exercise with rapid contraction alone on CMJ performance is still not known. Hence, further investigation is required to investigate the effects of performing multi-joint IST exercise with rapid contraction on athletic performance like sprinting and jumping.

Therefore, the aim of the study was to compare the effects of RIST with SIST on strength, sprinting and jump performance. It was hypothesized that there would be no difference in sprint and jump performance between interventions, but SIST will lead to a greater increase in peak force as compared to RIST.

Methods

Experimental Approach to the Problem

A randomised controlled trial design was used to compare the effects of two different IST methods on sprint and jump performance, and strength increment. Participants were required to complete one preliminary test session that included countermovement jump (CMJ), 30-m sprint, and isometric squat test (ISqT) at two different knee angles (90° and 120°). Subsequently, participants were randomly assigned to either control (Con), RIST or SIST groups. The Con group performed the same training program as both RIST and SIST but excluded the isometric squat exercise. The RIST and SIST groups had to complete 6 weeks of IST, twice per week. All participants completed 12 training sessions. At the end of the intervention, participants repeated the three tests.

Participants

Thirteen female and 23 male national floorball players (age 23.9 ± 3.1 years; stature 1.69 ± 0.08 m; body mass

64.6 ± 11.1 kg) were recruited for participation in this study. All participants had at least 3 years of experience in playing floorball competitively. Floorball is an indoor team sport that involves intermittent high intensity efforts. Study took place during the general preparation training phase of the periodisation cycle. A linear periodisation method was adopted for this macrocycle. Two female and one male participants from Con group dropped out from the study due to injury sustained during their sports training. The final sample size was 33. Participants were randomly assigned to Con (female $n=2$, male $n=7$), RIST (female $n=4$, male $n=8$) or SIST (female $n=4$, male $n=8$) training groups.

Sample power was computed (G*Power, v.3.1.9.2, University of Kiel, Germany) assuming an expected large effect size (for instance, $f=0.4$), 5% of error probability for 95% of power, three groups (i.e., three conditions), two measurements (i.e., pre- and post-test), correlation among repeated measures of 0.5 and nonsphericity correction of 1. Computation showed that a sample size of at least $n=21$ was required to obtain a statistical power of 0.8.

Inclusion criteria included: participants must be medically fit (no lower limb, lower back or neck injuries in the past 6 months); and is a team sport athlete in the national team (floorball). Exclusion criteria included: with medical contraindications deemed unfit flagged through physical activity and medical questionnaire that was done prior to research (including injuries in the past 6 months); non-team sport player; and not in the national team.

All participants were briefed on the requirements and risks involved in the study. Participants were required to sign a written informed consent prior to the initial testing session. The study commenced after obtaining ethical clearance from the Nanyang Technological University and Singapore Sport Institute Institutional Review Boards.

Training Program

All groups (Con, RIST, SIST) continued with their usual sport training, which included sport specific technic and tactical training 6 days per week. They were also instructed not to perform any other form of resistance training apart from those prescribed for the study. Training program was conducted by the same certified strength and conditioning coach in the Singapore Sport Institute Athletes Performance Gym.

Both RIST and SIST groups performed the same isometric squat exercise (Table 1). Both groups were instructed to push with maximum force and as fast as possible. The RIST group was not required to sustain the contraction while the SIST group was required to sustain the contraction for 3 s per repetition. Rest interval between sets was 2 min; between repetitions was 5 s for RIST and 10 s for SIST. Therefore, time to complete each set was ~ 60 s for both groups. Total contraction time per set was 10 s for RIST and was 15 s for SIST. To ensure that participants were performing maximal contraction, an electromyographic bio-feedback system ($f=2$ kHz; DELSYS™ Trigno Wireless Electromyography system, Delsys, Natick, MA, USA) was used to provide live electromyography data from the Trigno Avanti wireless surface sensors attached to the distal segment of the right vastus lateralis muscle. This was to allow participants to have the perception that their level of effort was being monitored. Principle of progressive overload was incorporated into the training program by varying the number of sets and/or repetitions for both training groups. Prior to all training sessions, participants completed 15 min of warm up including, jogging, side shuffles, high knee, lunge, squats and submaximal vertical jumps.

Table 1 Resistance training program

Exercises	Set × repetitions	Performed by
ISqT90 and ISqT120	2–3 × 10 × 1 s sustained contraction per angle	RIST
	2–3 × 5 × 3 s sustained contraction per angle	SIST
Single-leg stiff legged deadlift	2–4 × 6–10	Con, RIST, SIST
Weighted push up	2–4 × 6–10	Con, RIST, SIST
Weighted pull up	2–4 × 6–10	Con, RIST, SIST
Pallof press	2–3 × 10/side	Con, RIST, SIST
Side planks	2–3 × 10/side	Con, RIST, SIST
Bird dog	2–3 × 10/side	Con, RIST, SIST
Back extension	2–3 × 10	Con, RIST, SIST

Testing Sessions

Pre- and post-tests were conducted prior to and after completion of the 6 weeks training program, respectively. Pre-test was conducted at the beginning of the training program. Post-test was performed at least 72 h after the last session of the intervention program.

Prior to all testing sessions, participants were required to refrain from consuming alcohol and caffeine, and from participating in intensive training sessions within 24 h. Participants were also asked to avoid the consumption of any food and beverages other than water 2 h before each testing session. Testing sessions were conducted in the Singapore Sports Institute Athletes Performance Gym.

All testing sessions began with a 5 min moderate intensity jogging on an indoor running track, follow by ten repetitions of each lower body exercise including body weight squat, single leg stiff leg deadlift, side lunges and calf raise. Three minute of recovery period was given prior to commencing the test.

Countermovement Jump Test

The CMJ was performed on a system composed by force plate, linear position transducer and power cage (FT700 Isotronic Ballistic Measurement System, Fitness Technology, Adelaide, Australia). The system includes a force plate ($f = 600$ Hz; 400 series force plate, Fitness Technology, Adelaide, Australia) to record the peak force and power, and a linear position transducer (LPT) (PT5A-Fitness Technology, Adelaide, Australia) tethered to the right side of a wooden dowel with a weight 0.5 kg placed across the participant's shoulders, which was used to record vertical displacement and velocity. The vertical displacement of the linear transducer was determined as the jump height attained [29]. Participants attempted 3 jumps, separated by 30 s intervals. The highest jump height and the peak power that corresponded to the highest jump obtained were recorded [23].

30-m Sprint Test

The 30-m sprint from a two-point staggered start was administered as a test of sprint ability. All participants performed two trials separated by a 2 min recovery period. Timing gates (Swift Speedlight, Wacol, Australia) were set up at 0-, 5-, 10-, 20- and 30-m. Participants started from a position 0.2 m away from the timing gate to avoid accidentally triggering it. The best performance from the two trials was used for further analysis. Sprinting power was calculated using the analytical procedure proposed by Samozino et al. [26].

Isometric Squat Test (ISqT)

The ISqT was performed on a force plate ($f = 600$ Hz; 400 series force plate, Fitness Technology, Adelaide, Australia) to record the peak force (PF) and peak rate of force development (RFD). A sampling frequency of ≥ 500 Hz has been previously reported to provide accurate and reliable measurements of peak force, time-specific force values, and RFD at predetermined time bands during the IMTP [12]. Data on PF and RFD were collected for ISqT at knee flexion angles of 90° (ISqT90) and 120° (ISqT120) measured using a goniometer (full knee extension being 180°). Order of test for each knee angle position was randomized. Participants were asked to adopt the same feet placement as they would do for the back squat exercise. A bar was placed across the back in the same position as the back squat exercise and was fixed in the position that allowed the participants to adopt the two knee flexion angles. Participants were instructed to exert maximum tension against the bar as fast and as hard as possible upon tester's command, and to maintain the tension for a period of 4 s. Participants performed the ISqT at each knee flexion angle twice. Each attempt was separated by a 3 min recovery period [6]. Maximum force and maximum rate of force development obtained at each knee angle were recorded.

Statistical Analysis

All tested variables are expressed by Mean (± 1 SD) and 95% of confidence interval of the mean differences between pre- and post-test. Normality of all data was examined using the Shapiro–Wilk test of normality, and Levene's test was used to assess the heterogeneity of variance between groups. Test–retest reliability was assessed during each testing session using two-way mixed intraclass correlation coefficients (ICC) and typical error (TE) were used to assess the repeatability of performances between trials for CMJ, TT30 and ISqT. ICC values were deemed as highly reliable if $r \geq 0.80$ [11]. TE was calculated by dividing $\sqrt{2}$ with the standard deviation of the difference between trials [15].

Mixed ANOVAs (between $\times$ within-participant analysis; 3 training groups $\times$ 2 testing times; $P < 0.05$) was performed for each selected variable. All assumptions to run ANOVAs have been checked beforehand, including normality and sphericity. Degrees of freedom were corrected whenever sphericity's assumption was violated. A paired T test was used to determine any pre- and post-test within group difference and a one-way ANOVA was used to determine the differences in percentage change between groups *($P < 0.05$)*.

Effect size was computed by partial eta-squared (η_p^2) and deemed as: without effect if $0 < \eta_p^2 \leq 0.01$; small if $0.01 < \eta_p^2 \leq 0.06$; medium if $0.06 < \eta_p^2 \leq 0.14$ and; strong if $\eta_p^2 > 0.14$. Whenever suitable and appropriate, Cohen's d was also computed: (1) small effect size if $d = 0.20$–0.59; (2) medium effect size if $d = 0.6$–1.19; (3) large effect size if $d = 1.20$–1.99 and; (4) very large effect size if $d \geq 2.00$ [16]. Probabilities were also calculated to establish whether the true (unknown) differences were lower than, similar to, or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject SD) [16]. The quantitative chances of obtaining higher or lower differences were evaluated as follows: 1% = almost certainly not; 1%–5% = very unlikely; 5%–25% = unlikely; 25%–75% = possible; 75%–95% = likely; 95%–99% = very likely; and 99% = almost certain.

Results

Reliability of the Measures

All measured variables were normally distributed and demonstrated similar variance within each group and were highly reliable, based on the ICC > 0.8 criterion (Table 2). In two cases (ISqT90_RFD and ISqT120_RFD), the lower bound of the 95% CI was under the 0.8 cut-off value. TE in relation to the pre-test measures were 1.8% for CMJ height, 1.0% for TT30, 3.1% for ISqT90 PF, 6.0% for ISqT90 RFD, 3.5% for ISqT120 PF and 7.5% for ISqT120 RFD (Table 2).

Time × Group Interactions

Large time × group effect was obtained from ISqT120 for CMJ height ($P = 0.01$, $\eta_p^2 = 0.25$), PF ($P = 0.03$, $\eta_p^2 = 0.22$) and RFD ($P = 0.02$, $\eta_p^2 = 0.22$) (Table 3). On average, there was improvement in CMJ height. Similarly, improvement in PF and RFD obtained from ISqT120 were observed. Time × group effect in other measured variables showed medium-large effect sizes ($0.10 < \eta_p^2 < 0.96$).

Time Main and Simple Effects

Medium-large main effect for time was observed in CMJ height, PF obtained from ISqT90 and ISqT120, and RFD obtained from ISqT90 ($P < 0.01$, $0.27 < \eta_p^2 < 0.57$). Improvement in CMJ height was observed in both RIST ($P = 0.006$, $d = 0.30$) and SIST ($P < 0.001$, $d = 0.41$), but not in Con ($P = 0.961$, $d = 0.00$). There was a reduction in CMJ peak power for Con only ($P = 0.021$, $d = 0.37$). There was no change in TT5, TT10 and sprint relative peak power for all groups. TT30 was improved in SIST only ($P = 0.024$, $d = 0.12$). Improvements were observed in PF obtained from ISqT90 and ISqT120 in both RIST ($P = 0.039$ and < 0.001, respectively, $d = 0.33$ and 0.54, respectively) and SIST ($P = 0.002$ and < 0.001, respectively, $d = 0.61$ and 0.68, respectively), but not for Con ($P = 0.427$ and 0.255, respectively, $d = 0.09$ and 0.18, respectively). Similarly, there were improvements in RFD obtained from ISqT90 and ISqT120 in both RIST ($P = 0.01$ and 0.049, respectively, $d = 0.89$ and 0.87, respectively) and SIST ($P = 0.031$ and 0.022, respectively $d = 0.71$ and 0.58, respectively), but not in Con ($P = 0.266$ and 0.214, respectively, $d = 0.36$ and 0.45, respectively).

Table 2 Reliability for ISqT performance measures

	ICC (95% CI)	TE
CMJ height (cm)	0.96 (0.91; 0.98)	0.008
TT30 (s)	0.99 (0.97; 0.99)	0.04
ISqT90_PF (N)	0.99 (0.98; 1.00)	50.0
ISqT90_RFD (N/s)	0.81 (0.56; 0.92)	352.2
ISqT120_PF (N)	0.98 (0.94; 0.99)	70.4
ISqT120_RFD (N/s)	0.90 (0.76; 0.96)	561.0

95% CI 95% confidence intervals, *CMJ* countermovement jump, *ICC* intraclass correlations, *ISqT90* isometric squat at 90° knee angle, *ISqT120* isometric squat at 120° knee angle, *PF* peak force, *RFD* peak rate of force development, *TE* typical error, *TT30* 30-m sprint time

Group Main and Simple Effects

There was an overall small group main effect for all measurements ($0.51 < P < 0.99$, $0.01 < \eta_p^2 < 0.16$). The percentage change for CMJ height, TT30, ISqT90 PF and ISqT120 PF is illustrated in Fig. 1 and the magnitude based inference displayed in Table 4. Large differences were observed for change in CMJ height between Con and RIST ($P = 0.036$, $d = 3.12$), and Con and SIST ($P = 0.019$, $d = 3.54$). There were also large differences for change in TT30 ($P = 0.043$, $d = 3.00$), ISqT90 PF ($P = 0.034$, $d = 3.12$) and ISqT120 PF ($P = 0.003$, $d = 4.54$) and ISqT120 RFD ($P = 0.033$, $d = 1.36$) between Con and SIST only. Trivial to large differences were observed for all measures with TT30 and ISqT120 PF inferred as likely worse and CMJ PP and ISqT90 PF inferred as possibly worse when comparing RIST to SIST.

Discussion

The current study was the first to compare the effects of rapid contraction IST with and without sustained contraction on jumping and sprinting performance. There were time × group interactions for CMJ height, PF and RFD in ISqT120. Most of these variables improved over time. When the percentage changes in all variables were compared, RIST and SIST resulted in small to large, possibly to likely beneficial effect as compared to Con. In comparison between RIST and SIST, small to large, possibly to likely beneficial effect in favour of SIST were observed for CMJ PP, TT30, ISqT90 PF and ISqT120 PF. These higher probabilities of better effects (Table 4) for SIST showed a tendency for the existence of greater training effect.

Previous studies reported that IST with rapid contraction, but no sustained contraction, resulted in a greater improvement in the ability to generate force rapidly; while IST with 3 s sustained and non-rapid contraction resulted in greater gains in maximum strength [3, 30]. These findings were supported by the results of the current study. The change in PF achieved from ISqT90 and ISqT120 between RIST and SIST showed possibly and likely greater beneficial effect, respectively, in favour of SIST (Table 4). In corroboration with literature, the greater strength increment from SIST, as compared to RIST, was most likely due to the greater training volume as the total contraction time per set for SIST was 15 s as compared to 10 s for RIST [3, 30]. These results, therefore, provide evidence to support our claim that the difference in findings between Folland et al. [13] and Lee et al. [20] was due to the difference in the duration of isometric contraction. These studies also reported that rapid

Table 3 Analysis of the variance in the countermovement jump, 30-m sprint and isometric squat tests

	Con ($n=9$)			RIST ($n=12$)			SIST ($n=12$)			ANOVA		
	Pre-mean (SD)	Post-mean (SD)	95% CI	Pre-mean (SD)	Post-mean (SD)	95% CI	Pre-mean (SD)	Post-mean (SD)	95% CI	Time main effect	Group main effect	Time × group interaction
CMJ Height (cm)	36.4 (9.2)	36.4 (7.9)	−2.0; 2.1	36.2 (10.7)	39.3 (9.6)**	−5.1; 1.1	36.0 (9.5)	39.8 (8.9)**	−5.5; −2.1	$F=20.47$ $P<0.001$ $\eta_p^2=0.41$	$F=0.08$ $P=0.93$ $\eta_p^2=0.01$	$F=5.01$ $P=0.01$ $\eta_p^2=0.25$
CMJ PP (W)	3031.1 (642.3)	2827.3 (451.1)*	39.9; 367.8	3213.0 (768.3)	3063.5 (523.7)	−84.2; 383.2	2938.8 (578.5)	2976.2 (503.4)	−259.2; 184.5	$F=3.38$ $P=0.08$ $\eta_p^2=0.10$	$F=0.45$ $P=0.64$ $\eta_p^2=0.03$	$F=1.66$ $P=0.21$ $\eta_p^2=0.10$
TT30 (s)	4.57 (0.37)	4.58 (0.33)	−0.10; 0.01	4.48 (0.42)	4.46 (0.43)	−0.03; 0.06	4.51 (0.50)	4.45 (0.47)*	0.01; 0.11	$F=2.87$ $P=0.10$ $\eta_p^2=0.09$	$F=0.18$ $P=0.84$ $\eta_p^2=0.01$	$F=2.37$ $P=0.11$ $\eta_p^2=0.14$
Sprint Rel. PP (W/kg)	27.4 (5.1)	25.4 (5.9)	−0.3; 4.4	29.1 (7.4)	29.1 (7.5)	−0.8; 0.3	28.9 (0.85)	29.1 (0.79)	−1.7; 1.3	$F=2.17$ $P=0.15$ $\eta_p^2=0.07$	$F=0.54$ $P=0.59$ $\eta_p^2=0.04$	$F=2.87$ $P=0.07$ $\eta_p^2=0.16$
ISqT90 PF (N)	1550.9 (287.8)	1579.1 (314.6)	−105.9; 49.5	1593.3 (331.2)	1696.4 (302.5)*	−200.0; −6.2	1494.5 (311.8)	1686.0 (312.0)**	−346.9.0; −36.2	$F=11.31$ $P<0.001$ $\eta_p^2=0.27$	$F=0.203$ $P=0.82$ $\eta_p^2=0.01$	$F=2.11$ $P=0.14$ $\eta_p^2=0.12$
ISqT90 RFD (N/s)	4496.6 (1444.8)	5121.1 (1977.8)	−1829.9; 580.8	5490.4 (2476.7)	7672.8 (2400.9)*	−3228.6; −1136.2	5963.0 (2609.8)	7928.8 (2921.5)*	−3714.3; −217.2	$F=18.52$ $P<0.001$ $\eta_p^2=0.38$	$F=2.75$ $P=0.80$ $\eta_p^2=0.16$	$F=1.59$ $P=0.22$ $\eta_p^2=0.96$
ISqT120 PF (N)	1984.5 (442.5)	2078.6 (594.9)	−270.8; 82.7	1932.6 (452.6)	2171.0 (427.5)**	−335.0; −141.8	1865.3 (483.2)	2229.2 (578.0)**	−519.8; −208.1	$F=39.11$ $P<0.001$ $\eta_p^2=0.57$	$F=0.01$ $P=0.99$ $\eta_p^2=0.00$	$F=4.21$ $P=0.03$ $\eta_p^2=0.22$
ISqT120 RFD (N/s)	7481.8 (5052.2)	5669.4 (2668.4)	−1284.9; 4909.6	5966.3 (2712.3)	8933.7 (3961.8)*	−5935.1; 0.4	7092.7 (4503.7)	9428.6 (3453.7)*	−4266.6; −405.2	$F=2.79$ $P=0.11$ $\eta_p^2=0.09$	$F=4.23$ $P=0.51$ $\eta_p^2=0.04$	$F=4.23$ $P=0.02$ $\eta_p^2=0.22$

CMJ countermovement jump, *Con* control, *EIST* explosive contraction isometric training, *ES* Cohen's *d*, *95% CI* 95% confidence interval of the mean difference between pre- and post-test, *ISqT90* isometric squat at 90° knee angle, *ISqT120* isometric squat at 120° knee angle, *PF* peak force, *PP* peak power, *RFD* peak rate of force development, *SIST* sustain and explosive isometric training, *TT30* 30-m sprint time

*Denotees significant difference from Pre-test ($P < 0.05$)

**Denotees significant difference from Pre-test ($P < 0.01$)

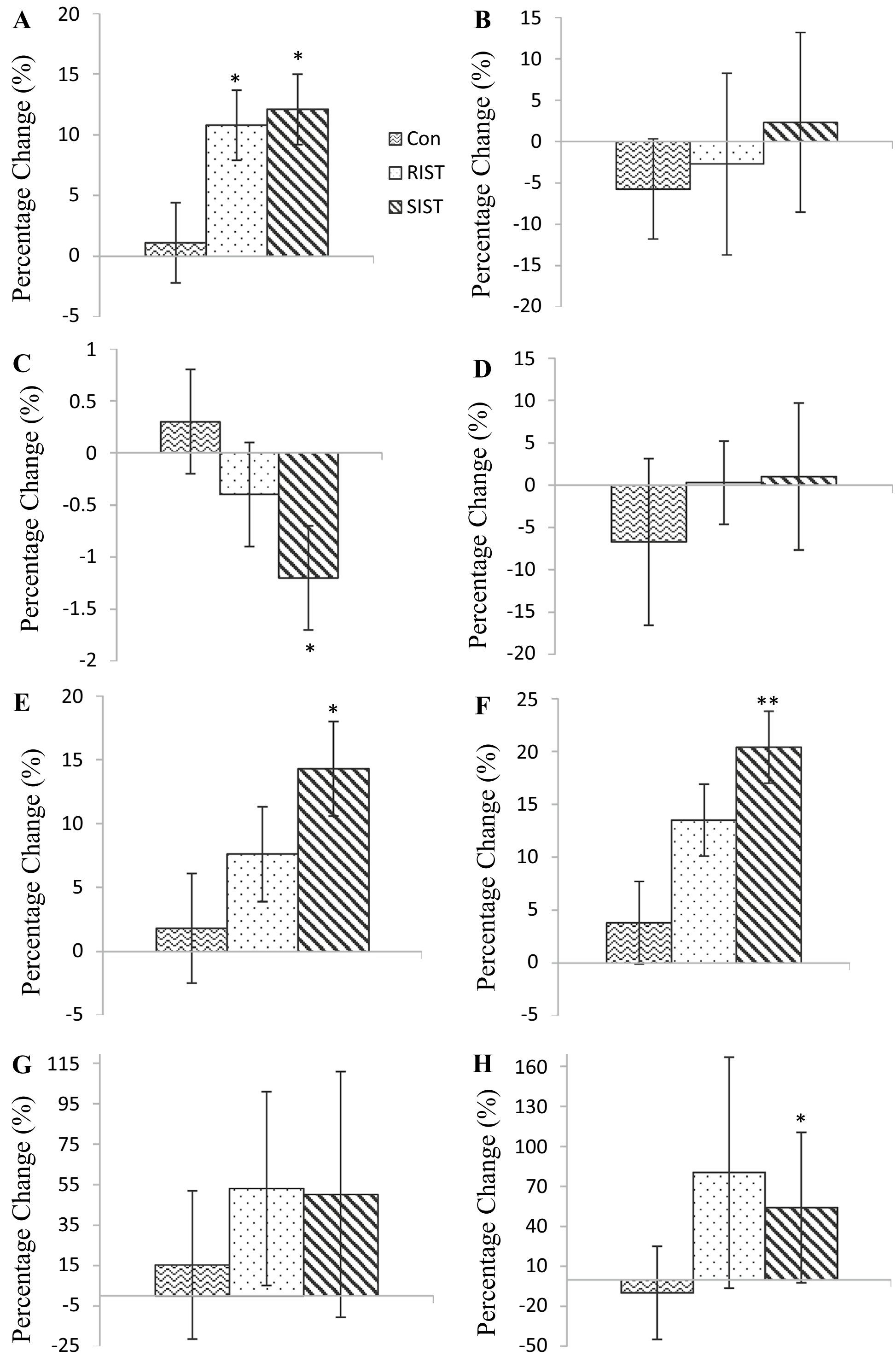

Fig. 1 Percentage change for: **a** CMJ height, **b** CMJ peak power, **c** TT30, **d** sprint peak power, **e** ISqT90 peak force, **f** ISqT120 peak force, **g** ISqT90 RFD, **h** ISqT120 RFD. *Significant difference from Con ($P<0.05$). **Significant difference from Con ($P<0.01$)

contraction method was more effective in improving the ability to generate force rapidly as compared to sustained contraction method. The current study was the first to investigate on the effects of a sustained contraction method executed rapidly. However, SIST possibly resulted in lower effect for the improvement of RFD achieved from ISqT120 as compared to RIST. A possible reason for this finding could be because functional adaptation to rapid contraction method (i.e. improved the ability to generate force rapidly) may be negated when combined with sustained contraction method, suggesting that there might be some interference effect [19].

Jump height has been reported to be strongly correlated with lower limb strength, and stronger individuals have been

Table 4 Magnitude-based inference on the changes in dynamic performance variables from pre- to post-test between groups

Comparisons	Changes observed for pre vs. post			
	P	*d*	Percent changes of better/trivial/worse effect	
CMJ height				
RIST vs. Con	0.050	3.12	93.6/5.5/0.9	Likely better
RIST vs. SIST	0.779	0.45	22.1/36.4/41.5	Unclear
SIST vs. Con	0.008	3.54	98.8/1.1/0.1	Very likely better
CMJ PP				
RIST vs. Con	0.468	0.34	59.4/29.1/11.5	Possibly better
RIST vs. SIST	0.270	0.46	5.8/20.9/73.3	Possibly worse
SIST vs. Con	0.060	0.91	92.4/6.5/1.1	Likely better
TT30				
RIST vs. Con	0.343	1.40	67.9/24.2/7.9	Possibly better
RIST vs. SIST	0.232	1.60	4.9/18.8/76.3	Likely worse
SIST vs. Con	0.048	3.00	93.8/5.4/0.8	Likely better
Sprint Rel. PP				
RIST vs. Con	0.044	0.90	72.4/10.4/17.2	Possibly better
RIST vs. SIST	0.809	0.10	23.2/36.8/40.0	Unclear
SIST vs. Con	0.071	0.83	91.2/7.5/1.3	Likely better
ISqT90 PF				
RIST vs. Con	0.166	1.45	82.1/14.6/3.4	Likely better
RIST vs. SIST	0.267	1.81	5.8/20.7/73.5	Possibly worse
SIST vs. Con	0.050	3.12	93.1/5.9/0.9	Likely better
ISqT90 RFD				
RIST vs. Con	0.064	0.89	92.1/6.8/1.2	Likely better
RIST vs. SIST	0.898	0.05	35.6/37.7/26.7	Unclear
SIST vs. Con	0.144	0.70	84.0/13.1/2.9	Likely better
ISqT120 PF				
RIST vs. Con	0.045	2.65	94.2/5.0/0.8	Likely better
RIST vs. SIST	0.170	2.03	3.4/15.0/81.6	Likely worse
SIST vs. Con	0.010	4.54	96.5/3.4/0.1	Very likely better
ISqT120 RFD				
RIST vs. Con	0.008	1.37	98.8/1.1/0.1	Very likely better
RIST vs. SIST	0.390	0.36	64.5/26.4/9.1	Possibly better
SIST vs. Con	0.008	1.36	98.8/1.1/0.1	Very likely better

reported to jump higher than weaker individuals [28]. The current results indicated that CMJ height was improved over time by 10.8% and 12.1% in RIST and SIST, respectively, with no difference in percentage change between the intervention groups. These magnitudes of improvement are comparable to studies that investigated the effects of heavy (70%–95% of 1 repetition maximum) dynamic squats and plyometric exercises on CMJ height in team sports athletes [9, 14, 25, 28]. This suggests that performing ISqT training using both RIST and SIST methods might be as effective as performing dynamic squat training in improving jumping performance in team sports athletes. The present finding is in agreement with some previous studies on IST [5, 7] but not others [3, 6, 17, 24]. Common factors present in the IST of the current research and studies that reported improvement in jump height after IST are, the use of multi-joint exercise, performing IST with rapid contraction and/or performing IST at multiple joint angles [5, 7]. These were factors missing in those that fail to report an improvement in jump height after performing IST [21].

Several studies have reported that PF and RFD achieved from ISqT were inversely correlated with sprint time [32, 33, 36]. However, this might be the first study to investigate the effects of ISqT on sprint performance. The results showed an improvement over time in TT30 in SIST but not in RIST. In regard to sprint relative peak power, a small effect size was observed for SIST ($d=0.24$). The 1.4% improvement in 30-m sprint time in the SIST was comparable to that from a study that reported soccer players significantly improved 40-m sprint time by ~ 1.2% after performing heavy squat and combined heavy squat and plyometric training [25]. The abilities to apply greater force and produce high RFD during ground contact are some of the characteristics that determine faster running speed [34, 35]. In addition, it has been reported that an increase in lower limb strength enhances sprinting performance [27]. Therefore, based on these past findings, the improvement in 30-m sprint observed in SIST may also be attributed to the improvement in maximal force and RFD development. The lower magnitude of strength increment and lack of improvement in 30-m sprint time observed in RIST supports this claim. This suggests that team sport athletes may perform squats using SIST method as an alternative to heavy dynamic squat for enhancing sprint performance.

The results from this study should be interpreted in light of some limitations. First, the amount of force produce for each repetition during IST would affect the magnitude of strength gain [3, 21, 30]. Therefore, the magnitude of strength gain was dependent on participants' compliance to perform each repetition with maximal effort. Although EMG live feedback during training was employed to give participants the perception that their effort was being monitored, force production was not measured. Second, although participants were athletes in the national team, they did not perform regular strength training prior to participating in the study. The magnitude of improvement in strength and dynamic performances might be smaller if participants had been resistance trained prior to participation [1]. Finally, although the current results showed greater improvement in strength and dynamic performances in SIST group, it is important to note that this could be attributed to the greater volume of training performed as compared to RIST (15 s vs. 10 s isometric contraction per set). It is not known if results would differ if total contraction time were to be equalised between the two training groups.

Conclusion

In summary, a trend of greater improvement in sprinting and strength performance in SIST as compared to RIST. In addition, the current study showed that ISqT executed with SIST resulted in similar magnitude of improvement for CMJ and sprint performance as heavy dynamic squat reported in previous studies. Therefore, it is recommended that athletes who wish to include IST into their training program adopt the SIST method if the objective is to enhance dynamic movement such as jumping and sprinting.

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