Journal of Science in Sport and Exercise
https://doi.org/10.1007/s42978-023-00241-0

ORIGINAL ARTICLE

Comparing the Acute Effects of an Session of Isometric Strength Training with Heavy Resistance Training on Neuromuscular Function

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Received: 11 November 2022 / Accepted: 27 June 2023

Abstract

Purpose This study compared the acute effects of a session of isometric strength training (ISO) with heavy resistance training (HRT) training on 20-m sprint, countermovement jump (CMJ) and isometric mid-thigh pull (IMTP) performance.
Methods Ten resistance-trained athletes (age: 26.7 ± 6.2 years, body mass: 71.5 ± 16.2 kg, height: 1.68 ± 0.10 m) performed baseline measures for 20-m sprint, CMJ and IMTP prior to either an ISO or HRT session. During both training sessions, participants performed back squats, Romanian deadlift and split squat. Post-test performances were measured 5 min and 24 h after each training session. Participants returned a week later to perform the other training session.
Results A significant time × condition effect was found for 20-m sprint time ($P = 0.007$) and IMTP peak force ($P = 0.003$). Main time effect was observed for 20-m sprint ($P < 0.001$), CMJ height ($P < 0.001$) and IMTP peak force ($P < 0.001$). HRT resulted in a greater increase in sprint time at 5 min (0.17 ± 0.12 vs. 0.06 ± 0.05 s, $P = 0.013$, $g = 1.15$) and 24 h (0.01 ± 0.09 vs. 0.00 ± 0.05 s, $P = 0.004$, $g = 1.32$) post-training as compared to ISO. Similarly, HRT resulted in a significantly larger reduction in IMTP peak force than ISO at both 5 min (− 363.3 ± 248.8 vs. − 98.9 ± 230.3 N, $P = 0.024$, $g = 1.06$) and 24 h (− 289.2 ± 256.2 vs. 37.9 ± 177.8 N, $P = 0.004$, $g = 1.42$) post-training. Total impulses generated during each exercise were greater during ISO than HRT ($P < 0.001$–0.006). Rating of perceived recovery post 24 h was higher in ISO than HRT ($P = 0.002$).
Conclusion The above results indicated that acute HRT led to a greater reduction in sprinting strength performance and lower perceived recovery post-24 h than ISO.

Keywords Sprint · Countermovement jump · Isometric mid-thigh pull · Strength · Recovery

Introduction

Isometric strength training (ISO) involves the generation of force by muscles without external movement [22]. This mode of resistance training has been reported to enhance sports-related performance such as cycling peak power output [19], endurance running [23], jumping [23, 25, 26], kayaking [24] and sprinting [25, 26]. Furthermore, it was reported that the improvement in strength was greater when half the volume of dynamic heavy resistance strength training (HRT) was replaced by ISO, when compared to performing HRT alone [24, 26]. Based on these lines of evidence, ISO is a viable option to be included in athletic training regimens.

Although the positive effects of ISO on athletic performance have been previously reported, the fatiguing effects of incorporating ISO are unclear, which is an important factor when

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Published online: 18 August 2023

planning for athletic training programmes. An isometric contraction is more energy efficient than an isotonic contraction [30, 34]; however, the acute change in neuromuscular function post-isometric contractions is unclear, when compared to post-concentric and -eccentric contraction. For example, Babault et al. [1] reported a greater decrement in maximal doublet twitch amplitude after a concentric contraction task as compared to an isometric contraction task. In other studies with an assessment of voluntary muscle contraction, Grosprêtre et al. [13] reported a greater reduction in plantar flexion force after elastic band exercise compared to isometric exercise; while Bisson et al. [3] reported no difference in plantar flexion force decrement after isometric or isokinetic plantar flexion tasks. One possible reason for the discrepancy could be due to the lack of eccentric contraction during the dynamic condition in the study by Bisson et al. [3], which was present in the study by Grosprêtre et al. [13]. Eccentric contraction is known to induce greater muscle soreness and reduction in force generation capability acutely [12, 33, 35].

From a practitioner's perspective, the current body of evidence is equivocal, without typical training modes (e.g. heavy resistance back squat) or intensities (e.g. > 80% of 1 repetition maximum) being employed in athletic strength training environments. Furthermore, the assessment modality lacks relevance to sports movement and hence the translation to athletic performance (such as jumping and sprinting performance) is not clear. Given that exercise-induced reductions in function can affect muscle activation and movement kinetics, it also has the potential to reduce the execution of technique, to reduce movement efficiency and hence to compromise the potential training quality for athletes [2, 10, 15–17, 33, 37].

The use of velocity-based training has gained popularity in recent years [31, 32]. This training method involved tracking the bar velocity while performing HRT, and the cessation of each set is determined by a specific velocity loss threshold [31, 32]. This method to perform HRT may allow for a more individualized prescription of training volume to optimise adaptations [31, 32]. Similarly, the use of multi-joint ISO in athletes' physical preparation has also increased in recent years, as studies have reported that the inclusion of ISO as compared to traditional strength training alone may result in greater strength improvement [24–26]. While the chronic effect of both methods on muscular performance has been relatively well studied, the acute effect on neuromuscular function is largely unknown.

Understanding the effects of different sport-specific training modalities can inform practitioners about the magnitude of the decline in neuromuscular function and plan appropriate training programs. Therefore, the aim of this study was to compare the acute effects of ISO with HRT on neuromuscular performance using exercises commonly performed during athletic strength training sessions. It was hypothesized that HRT will result in a greater decrement in performance at all time points, as the HRT protocol would include both concentric and eccentric contractions.

Methods

Participants

A convenient sample of eight male and two female resistance-trained athletes (age: 26.7 ± 6.2 years, body mass: 69.2 ± 16.2 kg, height: 1.67 ± 0.10 m, squat 1RM: 135.9 ± 41.76 kg) actively participating in various sports including athletics, cycling, squash and powerlifting, were recruited for the study. The athletes participated in the study during the pre-season of their respective sports. Inclusion criteria were: 18–45 years old, at least 2 years of resistance training experience, had prior experience in performing 1 repetition maximum (1RM) squat, had a 1RM squat of ≥ 1.5 times body weight, was free from injury. All participants signed the inform consent and parental consent was sought for participants below the age of 21 years old. Study commenced after obtaining approval from the institutional review board of the local sport institute.

Experimental Protocol

The study used a counterbalanced, crossover design. Participants were required to attend a familiarisation and four testing sessions including baseline testing, either ISO or HRT, and a follow-up day for post-test. During the familiarisation session, participants' 1RM squat were determined. Participants were also familiarised with the 20-m sprint, CMJ and isometric mid-thigh pull (IMTP) tests. Participants then returned to the laboratory seven days later to perform the first testing session. During this session, participants performed baseline testing in the following sequence, 20-m sprint, CMJ and IMTP, each separated by 5 min recovery. Participants were then randomly assigned to perform either the ISO or HRT 10 min after completing the IMTP. Once the ISO or HRT was completed, participants had 5 min of rest before they commenced the post-test measurement ($Post_{5min}$). Participants returned 24 h later to perform the three tests again to examine the level of recovery ($Post_{24h}$). Participants returned one week later to repeat the same procedure but performed the other mode of resistance training.

Procedure

Prior to all testing sessions, participants were required to refrain from consuming alcohol and caffeine for non-regular caffeine users, and from participating in strenuous training for 24 h prior to the visit. Participants were asked to avoid the consumption of any food and beverages other than water 2 h before each testing session. All testing was conducted at a similar time between sessions (± 1 h) to avoid a diurnal effect. All sessions commenced with 5 min of moderate intensity, self-paced jogging on an indoor running track, followed by 10 repetitions of each lower body exercises performed with a 20 kg Olympic barbell including squat, single leg Romanian deadlift, side lunges, calf raise and submaximal CMJ and pogo hops.

1 Repetition Maximum Squat

The squat was performed with participants starting from the upright position with the knees and hips fully extended, and the feet in parallel approximately shoulder-width apart; the barbell resting across the back at the level of the acromion. Participants descended in a continuous motion untill the upper thigh was parallel to the ground, then immediately raised back to the upright position. The test was preceded by three warm-up sets ranging from 2–10 repetitions and followed the procedure described by Haff & Triplett [14]. The 1RM was determined within 5 attempts to avoid fatiguing effects.

20-m Sprint

Participants performed 3 warm-up 20-m sprints at 50%, 70% and 90% of perceived maximum speed, followed by a 2 min passive recovery. Participants then performed two trials separated by a 2 min recovery period. Timing gates (Swift Speedlight, Wacol, Australia) were set up at 0- and 20-m. Participants started 0.2 m from the gate to prevent premature triggering of the initial start gate, with a two-point staggered start. The average time obtained for the 2 trials was used for further analysis. If the obtained time from the second trial was not within 5% of the first, a third trial was performed.

Countermovement Jump Test

Prior to the test, athletes performed three repetitions of CMJ at 90% of perceived maximal effort. The CMJ was performed on dual force plates (Force Decks, VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. During the CMJ, athletes were asked to keep their arms akimbo to eliminate arm swing and maintain their back upright to reduce angular displacement of the hips. Athletes performed 3 jumps, separated by 30 s rest intervals. Dependent variables included jump height (calculated from the velocity of the centre of mass at take-off) using the impulse-momentum relationship, mean propulsion force (MPF), time to take off (TTO), propulsion phase time (PPT) and countermovement depth. The average value of all three trials will be recorded and analyzed.

Isometric Mid-Thigh Pull

The IMTP was performed on the same dual force plates fitted onto a customised rack. Participants were asked to adopt a posture that reflects the start of the second pull of the clean Olympic lifting technique, resulting in a knee flexion angle of 125°–145° and hip flexion angle of 140°–150° stance. The IMTP testing procedure was previously described by Comfort et al. [9]. Participants performed the IMTP twice, with each attempt separated by a 2 min recovery period. The average peak force generated by the two trials was recorded and analyzed. In addition, force at 100, 150 and 200 ms ($Force_{100}$, $Force_{150}$ and $Force_{200}$, respectively) from the onset of pull was determined for each trial. The onset of pull was based on an increase of > 5 standard deviation (SD) of the participant's body mass [11].

Perceived Recovery

Participants were asked to rate their perceived recovery prior to all warm up on all testing sessions and 24 h post-training using the perceived recovery status scale (PRS) [20]. Participants were presented with a continuous 100 mm visual analogue scale with descriptors including ''not at all recovered'' at the 0 mm mark, ''moderately recovered'' at the 50 mm mark, and ''very well recovered'' at the 100 mm mark [20].

Perceived Rate of Exertion (RPE)

Participants were asked to provide their perceived rate of exertion (RPE) based on the CR-10 RPE scale 5 min after completing each training session [4]. A rating of 0 was associated with no effort and a rating of 10 was associated with maximal effort.

Resistance Training

Participants performed three exercises during each training session (Table 1). These exercises were selected because they represent all three fundamental movements of the lower limb, including squat, hinge and lunge [6]. All exercises were performed on the same dual force plate to measure the total impulse produced for each condition as an indication of the level of exertion. During the ISO condition, participants performed the back squat at four different knee angles, and Romanian deadlift and split squat at three different knee angles. ISO was performed at multiple joint positions because a previous study reported greater

Table 1 Training program for ISO and HRT

Condition	Exercise	Intensity	Sets × repetitions
ISO	Isometric squat at 60°, 90°, 120° and 150° knee angle	Maximal voluntary contraction	1 × 5 × 3 s per angle
	Isometric split squat at 70°, 100° and 130° knee angle		
	Isometric Romanian deadlift at 90°, 110° and 130° hip angle		
HRT	Back Squat	85% 1RM	4 × 20% velocity loss threshold
	Split Squat	40% 1RM squat	3 × 20% velocity loss threshold
	Romanian deadlift	95% 1RM squat	

improvement in dynamic performance after ISO with multiple joint positions when compared to single joint positions [27]. They were required to exert maximal force against a stationary bar as fast as they could for 5 repetitions at each position. Each repetition was sustained for 3 s with 3 s rest in between repetitions, and 2 min rest between sets [23–27]. For the HRT condition, the number of repetitions performed during each set was based on a 20% mean velocity loss from the first repetition of each set. For example, if the participant's attained a 0.5 m/s during the first repetition of the back squat, the set ended when the lifting velocity dropped to ≤ 0.4 m/s. This threshold of velocity loss was selected because previous studies reported greater adaptations for strength, power and hypertrophy when a 20% velocity loss threshold was used compared to other velocity loss thresholds (0%, 10% and 40%) [31, 32]. Similar to ISO, participants were instructed to perform the concentric phase as fast as they could for each repetition. The range of movement for each exercise during HRT is as follows: back squat—lowered till upper thighs were parallel to ground (~ 60° knee angle), split squat—lowered till knee angle 70°, Romanian deadlift—lowered till bar was just below patella tendon (~ 90° hip angle). A linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) was used to monitor the lifting velocity during HRT. The range of repetitions performed during HRT were as follows: back squat—3–5, Romanian deadlift—3–5, split squat—5–7.

Statistical Analysis

All tested variables are expressed as Mean (± 1 SD) and 95% of confidence intervals. Test–retest reliability was assessed using two-way mixed intraclass correlation coefficients (*ICC*) and coefficient of variation (*%CV*). *ICC* values were deemed as poor, moderate, good, or excellent if the lower bound 95%CI of *ICC* values were < 0.50, 0.50–0.74, 0.75–0.90, or > 0.90, respectively [21]. Acceptable within-session variability was classified as < 10% [8]. A two-way analysis of variance (ANOVA) with repeated measures and Bonferroni *post-hoc* analysis was used to assess the performance change in all measures. One-way ANOVA analysis was used to compare the absolute change in all variables. All variables were tested for normality and homogeneity of variance using the Shapiro–Wilk test and Levene's test of homogeneity of variance as well as Mauchly's test of sphericity before continuing subsequent statistical analysis. Cohen's d was calculated as the standardized effect size for mean comparisons, and deemed a: (i) trivial effect size if $d < 0.20$; (ii) small effect size if $d = 0.20$–0.49 and; (iii) moderate effect size if $d = 0.50$–0.80; (iv) large effect size if $d > 0.80$ [7].

Results

Reliability

The reliability data for all measured variables are displayed in Table 2. Good to excellent reliability was observed for 20-sprint time and CMJ height, MPF, IMTP peak force, force at 100, 150 and 200 ms. Moderate reliability was observed for CMJ TTO, PPT, countermovement depth and IMTP force at 100 ms. All measured variables had < 10% variability.

Table 2 Reliability data

Variables	*ICC*	95%CI	*%CV*	95%CI
20-m sprint time (s)	0.97	0.93–0.99	1.3	1.0–1.6
CMJ Height (cm)	0.97	0.94–0.99	4.3	3.5–5.6
CMJ MPF (N)	0.97	0.94–0.99	6.0	4.9–7.9
CMJ TTO (s)	0.87	0.73–0.95	5.3	4.3–6.9
CMJ PPT (s)	0.79	0.58–0.92	3.9	3.2–5.1
CMJ Countermovement Depth (cm)	0.95	0.90–0.98	4.0	3.2–5.1
IMTP Peak Force (N)	0.97	0.94–0.99	4.6	3.7–5.9
$Force_{100}$ (N)	0.82	0.64–0.93	9.2	7.5–12.1
$Force_{150}$ (N)	0.91	0.81–0.97	8.3	6.7–10.8
$Force_{200}$ (N)	0.96	0.90–0.98	5.1	4.2–6.7

CMJ countermovement jump, $Force_{100}$ force at 100 ms, $Force_{150}$ force at 150 ms, $Force_{200}$ force at 200 ms, *IMTP* isometric mid-thigh pull, *MPF* mean propulsive force, *PPT* propulsive phase time, *TTO* time to take off

Table 3 Performance measures of all variables

Variables	ISO			HRT			Time	Time × condition	Condition
	Pre	$Post_{5min}$	$Post_{24h}$	Pre	$Post_{5min}$	$Post_{24h}$			
20-m sprint time (s)	3.28 (0.25)	3.35 (0.26)*	3.28 (0.26)	3.27 (0.22)	3.45 (0.26)$^{\$\$}$	3.38 (0.25)$^{\$\$}$	$P<0.001$	$P=0.007$	$P=0.506$
CMJ Height (cm)	38.3 (7.0)	35.4 (6.7)*	37.9 (6.4)#	38.5 (7.3)	32.3 (5.5)$^{\$\$}$	36.0 (6.5)$^{\$\$\Psi}$	$P<0.001$	$P=0.066$	$P=0.581$
CMJ MPF (N)	1496.1 (350.3)	1488.3 (354.1)	1487.6 (353.1)	1472.5 (322.7)	1364.9 (305.1)$^{\$\$}$	1411.4 (304.3)$^{\$\$}$	$P<0.001$	$P=0.004$	$P=0.621$
CMJ TTO (s)	0.693 (0.063)	0.680 (0.066)	0.699 (0.058)	0.726 (0.093)	0.753 (0.117)	0.755 (0.091)$^{\$}$	$P=0.170$	$P=0.103$	$P=0.151$
CMJ PPT (s)	0.244 (0.014)	0.241 (0.022)	0.245 (0.015)	0.248 (0.017)	0.256 (0.020)	0.261 (0.015)$^{\$\$}$	$P=0.068$	$P=0.103$	$P=0.116$
CMJ Countermovement Depth (cm)	30.4 (4.7)	28.8 (4.6)	30.9 (3.2)##	31.2 (5.5)	30.2 (5.3)	31.6 (5.2)$^{\Psi\Psi}$	$P=0.001$	$P=0.795$	$P=0.647$
IMTP Peak Force (N)	2629.5 (569.5)	2530.6 (518.1)	2667.4 (583.8)##	2677.85 (621.4)	2314.6 (527.0)$^{\$\$}$	2388.7 (509.5)$^{\$\$}$	$P<0.001$	$P=0.003$	$P=0.576$
$Force_{100}$ (N)	1259.8 (285.7)	1206.7 (243.2)	1239.0 (286.9)	1272.35 (292.9)	1128.9 (238.7)$^{\$}$	1211.6 (272.0)$^{\$}$	$P=0.011$	$P=0.348$	$P=0.793$
$Force_{150}$ (N)	1761.75 (444.3)	1660.1 (492.3.0)	1720.4 (540.9)	1783.1 (421.4)	1496.8 (386.0)$^{\$\$}$	1567.1 (402.0)$^{\$\$}$	$P=0.002$	$P=0.100$	$P=0.594$
$Force_{200}$ (N)	2111.8 (477.7)	1947.0 (451.1)	2003.8 (505.6)	2104.7 (486.8)	1844.8 (470.1)$^{\$\$}$	1895.3 (416.0)$^{\$\$}$	$P<0.001$	$P=0.658$	$P=0.774$

*Denotes significant difference from ISO Pre ($P<0.05$)

**Denotes significant difference from ISO Pre ($P<0.01$)

#Denotes significant difference from ISO $Post_{5min}$ ($P<0.05$)

##Denotes significant difference from ISO $Post_{5min}$ ($P<0.01$)

$^{\$}$Denotes significant difference from HRT Pre ($P<0.05$)

$^{\$\$}$Denotes significant difference from HRT Pre ($P<0.01$)

$^{\Psi}$Denotes significant difference from HRT $Post_{5min}$ ($P<0.05$)

$^{\Psi\Psi}$Denotes significant difference from HRT $Post_{5min}$ ($P<0.01$)

20-m Sprint Performance

Significant time × condition and time effect were observed for 20-m sprint time (Table 3). However, condition effect was not observed. Time effects showed a significant increase in sprint time between baseline and $Post_{5min}$, and baseline and $Post_{24h}$ for HRT. Significant increase in sprint time was observed between baseline and $Post_{5min}$ only for ISO. HRT resulted in greater increase in sprint time at $Post_{5min}$ (0.17 ± 0.12 vs. 0.06 ± 0.05 s, $P=0.013$, $g=1.15$) and $Post_{24h}$ (0.01 ± 0.09 vs. 0.00 ± 0.05 s, $P=0.004$, $g=1.32$) as compared to ISO (Fig. 1).

Countermovement Jump Performance

Significant main-time effect was observed for CMJ height, MPF, and countermovement depth (Table 3). Significant time × condition effect was observed for MPF only, while no condition effect was observed for all CMJ measures. For CMJ height, the simple time effect showed a decrease at $Post_{5min}$ and $Post_{24h}$ from baseline, and an increase at $Post_{24h}$ from $Post_{5min}$ for HRT. A decrease in jump height at $Post_{5min}$ from baseline, and an increase at $Post_{24h}$ from $Post_{5min}$ was observed for ISO. Baseline measures for MPF were lower at $Post_{5min}$ and $Post_{24h}$ as compared to baseline for HRT but not for ISO. There were increases in TTO at $Post_{24h}$ and PPT at $Post_{24h}$ from baseline for HRT. Countermovement depth was higher at $Post_{24h}$ than at $Post_{5min}$ for both ISO and HRT. When a change in jump height was compared, there were large but insignificant difference between HRT and ISO at $Post_{5min}$ (-6.2 ± 4.6 vs. -2.9 ± 2.9 cm, $P=0.065$, $g=0.83$) and $Post_{24h}$ (-2.5 ± 2.2 vs. -0.4 ± 2.4 cm, $P=0.053$, $g=0.87$) (Fig. 1).

Isometric Mid-Thigh Pull Performance

Significant time × condition effect was observed for peak force, while a significant time effect was observed

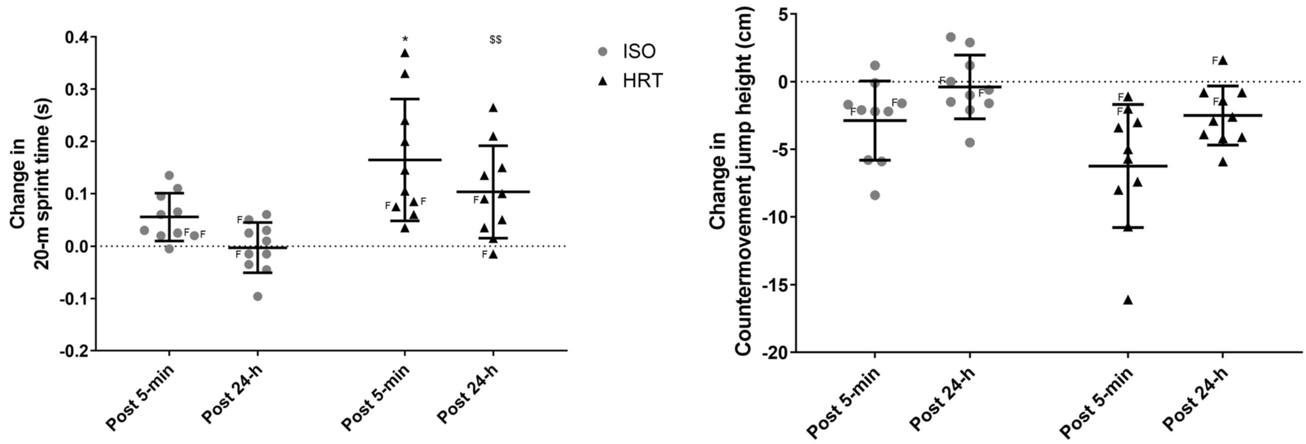

Fig. 1 Change in 20 m sprint and countermovement jump height. *Denotes significantly different from ISO $Post_{5min}$ ($P < 0.05$). $^{\$\$}$Denotes significantly different from ISO $Post_{24h}$ ($P < 0.01$). [F]Denotes female participant

for all IMTP measures (Table 3). No condition effect was observed. Simple time effect for peak force showed a decrease at $Post_{5min}$ and $Post_{24h}$ from baseline in HRT. While no decrease in peak force from baseline to $Post_{5min}$ was observed in ISO, there was an increase in peak force at $Post_{24h}$ from $Post_{5min}$. $Force_{100}$ decreased at $Post_{5min}$ and $Post_{24h}$ from baseline in HRT. $Force_{150}$ also decreased at $Post_{5min}$ and $Post_{24h}$ from baseline in HRT. Similarly,

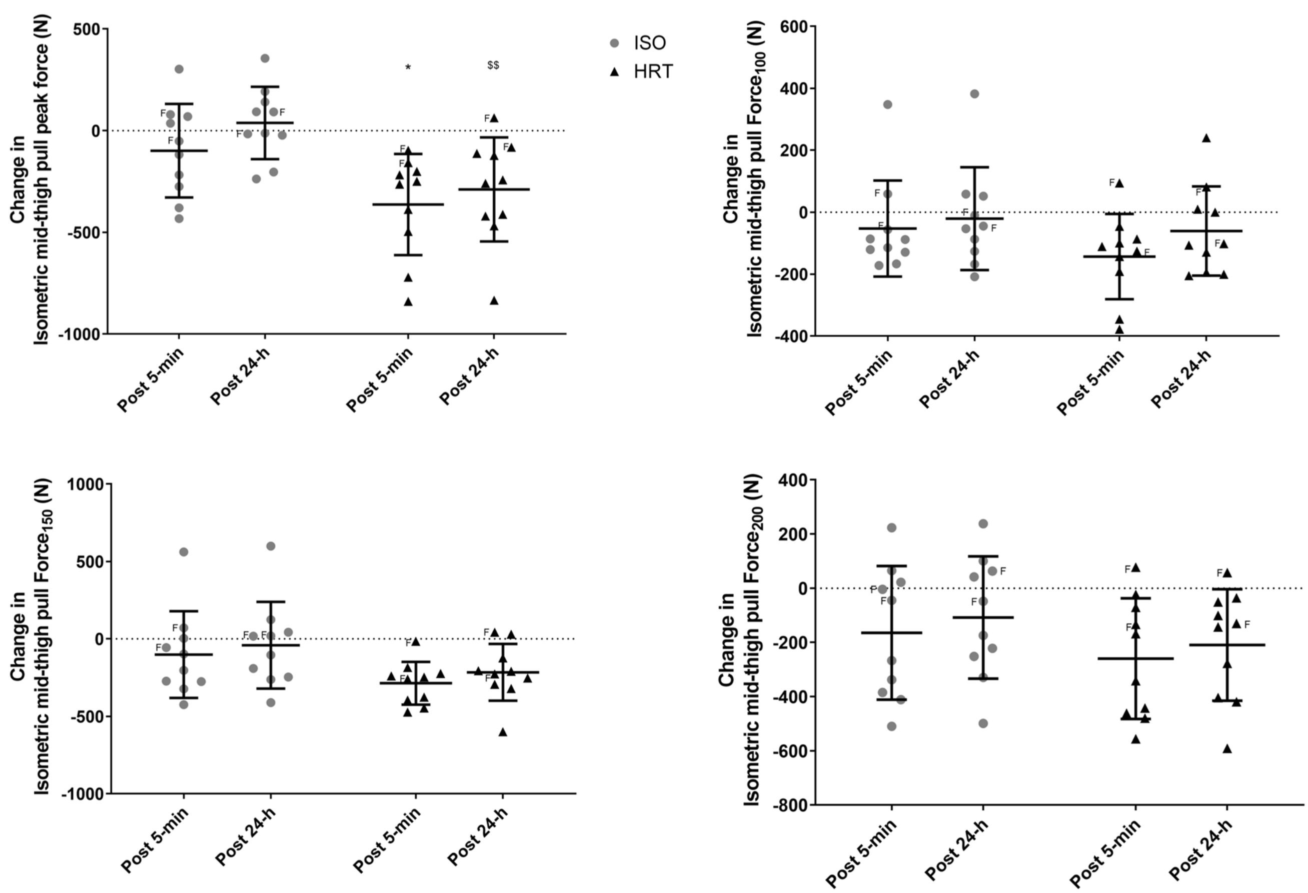

Fig. 2 Change in isometric mid-thigh pull measures. *Denotes significantly different from ISO $Post_{5min}$ ($P < 0.05$). $^{\$\$}$Denotes significantly different from ISO $Post_{24h}$ ($P < 0.01$). [F]Denotes female participant

$Force_{200}$ decreased at $Post_{5min}$ and $Post_{24h}$ from baseline in HRT. No change in early force development was observed in ISO at any time point. When comparing the change in peak force, HRT resulted in greater reduction than ISO at both $Post_{5min}$ (− 363.3 ± 248.8 vs. − 98.9 ± 230.3 N, $P = 0.024$, $g = 1.06$) and 24 h (− 289.2 ± 256.2 vs. 37.9 ± 177.8 N, $P = 0.004$, $g = 1.42$) (Fig. 2). There was no significant difference in the change for $Force_{100}$, $Force_{150}$ and $Force_{200}$ between conditions at any time points ($P = 0.078$ to 0.806, $g = 0.11$ to 0.80).

Impulse

Impulses produced during ISO and HRT are displayed in Table 4. The results showed that the impulses produced for all exercises were significantly higher in ISO than HRT.

Rating of Perceived Exertion and Recovery

There was no significant difference in RPE between conditions (Table 4). Similarly, there was no difference in $PRS_{baseline}$ between conditions. However, PRS_{post24} was significantly higher in ISO than in HRT.

Discussion

The purpose of the study was to compare the acute effects of ISO with HRT on neuromuscular performance using exercises commonly performed during athletic strength training sessions. The current findings showed that HRT resulted in a greater decrease in performance for the 20-m sprint and IMTP at both $Post_{5min}$ and $Post_{24h}$ than ISO. In addition, while no difference in the level of perceived exertion was observed between conditions, HRT resulted in a lower rating for perceived recovery despite exerting lower impulse during the training session. Based on these findings, our hypothesis was supported.

To overcome the limitations of previous studies, the current study used ISO and HRT methods that have been shown to induce adaptations that would benefit strength and sports performance [23–27, 31, 32]. Specifically, the ISO protocol used in this study was reported to benefit both strength and dynamic performance [23–27]. Furthermore, the included ISO has resulted in greater improvement in both strength and dynamic performance than in traditional strength training alone over a 24-week period [26]. The current results showed that ISO did not lead to changes in all IMTP measures at either $Post_{5min}$ or $Post_{24h}$. However, HRT resulted in a significant decrease in IMTP peak force and all early force development measures at both time points. Furthermore, the decrease in peak force at both time points was significantly larger after HRT than ISO, indicating a greater fatigue effect after HRT. This was despite a greater amount of total impulse produced by ISO. One possible reason for the greater impairment in strength performance after HRT could be due to the heavy eccentric loading, which is known to induce greater levels of muscle soreness than other modes of muscle contraction [12, 33, 35]. For example, Raeder et al. [33] reported that the eccentric overload training protocol resulted in the greatest decrease in maximal voluntary isometric contraction $Post_{5min}$ and $Post_{24h}$, when compared to other resistance training protocol. The higher level of soreness after HRT, as reflected by the lower PRS, possibly resulted in a lower force generation capability [35]. Previous studies with similar HRT protocols also showed impaired strength performance 24 h after training, which was attributed to both central and peripheral fatigue [15, 18, 36]. It was also indicated that HRT might require up to 72 h for a neuromuscular function to recover fully [36]. It is, however, not possible to comment on the mechanism for the decrease in strength performance after HRT in this study, since no specific assessment was performed to investigate this factor. In contrast to HRT, and to the best of our knowledge, no study was conducted to investigate the acute neuromuscular effect of ISO using a protocol similar to the current one. Notwithstanding, Grospretre et al. [13] reported that the decrease in the maximal force of the plantar flexor after 120 s of intermittent maximal intensity isometric plantar flexion was probably due to central fatigue. Given that no decrease in peak force was observed in ISO, it seems that the recovery period was sufficient for the participants to recover from the fatigue induced by the ISO protocol.

Table 4 Measures for training effort and perceived recovery

Variables	ISO	HRT	*P*	*g*
Squat impulse (N·s)	125,365.0 (42,560.3)	76,959.4 (24,734.3)**	0.006	1.33
Romanian deadlift impulse (N·s)	102,179.4 (12,384.7)	60,519.2 (22,109.0)**	< 0.001	2.23
Split squat impulse (N·s)	108,925.5 (19,013.1)	62,475.6 (19,767.6)**	< 0.001	2.29
Rating of perceived exertion	6.9 (1.5)	7.6 (1.1)	0.206	0.51
Rating of perceived recovery (Pre) (mm)	75 (14)	80 (12)	0.402	0.37
Rating of perceived recovery (Post) (mm)	62 (12)	41 (13)**	0.002	1.61

**Denotes significant difference from ISO($P < 0.01$)

While peak force is a common measurement used to indicate levels of fatigue, it has been suggested that rate at which force is developed is more sensitive to fatigue [5, 38]. In the current study, significant decreases in early force development at 100, 150 and 200 ms were observed in HRT only. However, unlike peak force, changes in early force development showed no significant difference between conditions. In addition, while peak force increased by ~ 2.4% at $Post_{24h}$ from baseline for ISO, early force development remained negative (− 1.1% to − 5.7%). Although this decrease in early force development in ISO was not statistically different from the baseline, it does provide some support that the rate of force development is a more sensitive measurement to indicate neuromuscular fatigue. The current results for ISO also differed from Buckthorpe et al. [5], which showed a decrease in early force development after performing ISO at a similar intensity and volume. One possible reason for this discrepancy could be due to the fact that the current ISO protocol involved several compound exercises that allowed for distribution of load to different muscles, while the protocol by Buckthorpe et al. [5] involved only one single joint exercise concentrating on a single muscle. With the same intensity and volume of contractions performed by a single muscle, the protocol by Buckthorpe et al. [5] would conceptually result in greater levels of fatigue compared to the current protocol. Nevertheless, the current findings indicated that HRT as compared to ISO, resulted in a greater decrease in strength performance at 24 h. Hence, athletes and coaches should be aware that activities that require high force or rate of force development can be impaired for at least 24 h post-HRT, while minimal change occurs following ISO.

Findings from previous studies investigating the acute effect of HRT on CMJ performance have shown conflicting results, with some showing no changes [17, 37], while others showing a decrease in CMJ height and other performance measures [15, 16, 33]. This discrepancy is likely due to the different training protocols adopted by the different studies. Based on the findings from Helland et al. [15] and Raeder et al. [33], CMJ height decreased by 4.5–8.2 cm at $Post_{5min}$ and 3.2–3.7 cm at $Post_{24h}$. These results were comparable to the current findings from HRT. In addition to a decrease in jump height, Helland et al. [15] also reported a significant decrease in the rate of force development, concentric and eccentric force during CMJ. The decrease in jump height was likely due to a reduced ability to generate force rapidly over the propulsion phase [15]. Similarly, the current results showed decreases in MPF but greater TTO and PPT. These findings also indicate that the cause of the decrease in jump height in the current study is comparable to fundings from other studies [15]. In addition, the decrease in CMJ MPF was in concurrent with the decrease in IMTP measures. This reflects the importance of both high force generation and rapid force application in jump performance. While CMJ height decreased $Post_{5min}$ and $Post_{24h}$ in HRT, it only decreased at $Post_{5min}$ in ISO. In contrast to HRT, where jump height was likely due to the inability to generate sufficient propulsive force, no other changes in CMJ variables accompanied the decline in jump height for ISO. Hence, the change in jump height was likely a consequence of the combined effect of insignificant changes in MPF and PPT, which resulted in decreased propulsive impulse that led to the observed change in jump height.

Sprint ability is an important physical attribute for the performance of many sports. The ability to excel in the acceleration phase of sprinting relies on the capacity to produce propulsive force rapidly within a brief period (< 150 ms) [28]. Therefore, similar to CMJ, reductions in force generation capability would likely result in a decrease in performance [29]. Indeed, Morin et al. [29] reported a reduction in horizontal and total force, and technical ability to apply force when performing 6 s sprints in a fatigued state. To the knowledge of the authors, only Helland et al. [15] investigated the effects of an HRT session on sprint acceleration performance. The authors reported an increase in sprint time at $Post_{5min}$ and $Post_{24h}$ [15]. Although the study did not measure sprint-specific performance variables, the simultaneous decrease in jump height and squat peak power indicated that the reduced force generation capability was likely responsible for the increased sprint time. Similarly, the current findings showed an increase in sprint time at $Post_{5min}$ and $Post_{24h}$ in the HRT condition. This was also associated with decreased CMJ height and IMTP peak force and early force development. In the ISO condition, sprint time only increased at $Post_{5min}$, which was similar to the finding for CMJ height. In addition, the changes in sprint time also showed greater performance decrement at both $Post_{5min}$ and $Post_{24h}$ in HRT than ISO. This further indicates that participants had greater neuromuscular fatigue after HRT than after ISO, and were able to recover faster from ISO than from HRT. In view of this, coaches should avoid planning activities that include high-intensity ballistic movement into the training program within 24 h of HRT as performance will likely be compromised. Instead, where high-intensity ballistic movements might be required in the following day, ISO provides a viable alternative to reduce the possibility of a compromised performance.

Several limitations should be noted while interpreting the current findings. Firstly, the results of the study may not be generalised to elite high-performance athletes due to the nature of the recruited participants in the study. Secondly, it has been previously reported that females may have greater resistance to fatigue as compared to males [18]. The current study was not able to perform such analysis due to the low number of female participants. Finally, it was not possible to match the volume and intensity of HRT and ISO due to the different modes of muscle contraction. Hence, a well-established protocol was adopted for each mode of contraction, with the purpose of optimising strength adaptations to increase the ecological validity of the study.

Conclusion

The current results showed that decreases in sprint, jump and strength performance persist 24 h post cessation of training in HRT but not ISO. This was despite the greater amounts of total impulse generated during ISO. In view of this, it is recommended that sports coaches should plan for a low to moderate-intensity sport training session that does not require athletes to exert high and rapid force within 24 h post-HRT. However, if coaches have to include a strength training session within a 24 h period prior to a high-intensity sports training, they have the option of selecting ISO. In addition, coaches may plan to substitute a session of HRT with ISO in the weekly program or replace part of the HRT exercises with ISO exercises within a session, to reduce athletes' level of fatigue. Furthermore, ISO may also be incorporated into the program in the later phase of the training cycle to minimise fatigue, injury risk while still maintaining maximum strength.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42978-023-00241-0.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Availability of data and material The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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