Modulation of Countermovement Jump–Derived Markers of Neuromuscular Function With Concurrent vs. Single-Mode Resistance Training

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ABSTRACT

Pattison, KJ, Drinkwater, EJ, Bishop, DJ, Stepto, NK, and Fyfe, JJ. Modulation of countermovement jump–derived markers of neuromuscular function with concurrent vs. single-mode resistance training. *J Strength Cond Res* 34(6): 1497–1502, 2020—This study assessed changes in countermovement jump (CMJ)-derived markers of neuromuscular function with concurrent training vs. resistance training (RT) alone and determined associations between changes in CMJ parameters and other neuromuscular adaptations (e.g., maximal strength gain). Twenty-three recreationally active men performed 8 weeks of RT alone (RT group, $n = 8$) or combined with either high-intensity interval training cycling (HIIT + RT group, $n = 8$) or moderate-intensity continuous cycling (MICT + RT group, $n = 7$). Maximal strength and CMJ performance were assessed before (PRE), after 4 weeks of training (MID), and >72 hours (maximal strength) or >5–7 days (CMJ performance) after (POST) the training intervention. Improvements in CMJ relative peak force from both PRE to MID and PRE to POST were attenuated for both HIIT + RT (effect size [ES]: −0.44; ±90% confidence limit, ±0.51 and ES: −0.72; ±0.61, respectively) and MICT + RT (ES: −0.74; ±0.49 and ES: −1.25; ±0.63, respectively). Compared with RT alone, the change in the flight time to contraction time ratio (FT:CT) was attenuated from PRE to MID for MICT + RT (ES: −0.38; ±0.42) and from PRE to POST for both MICT + RT (ES: −0.60; ±0.55) and HIIT + RT (ES: −0.75; ±0.30). PRE to POST changes in both CMJ relative peak force and flight time: contraction time (F:C) ratio were also associated with relative 1 repetition maximum leg press strength gain ($r^2 = 0.26$ and 0.19, respectively). These findings highlight the utility of CMJ testing for monitoring interference to improvements in neuromuscular function with concurrent training.

Key Words: fatigue, interference, adaptation, strength, power, monitoring

Introduction

Exercise training promotes physiological adaptations specific to the mode of exercise performed. Resistance (i.e., strength) training improves neuromuscular function, manifesting as both enhanced force production capacity and rates of force development (6), whereas endurance training favors metabolic adaptations with less influence on neuromuscular function (9). Integrating both resistance and endurance training into an exercise regime, known as concurrent training, can impair training-induced improvements in measures of neuromuscular function, including dynamic 1 repetition maximum (1RM) strength and isometric rates of force development, relative to resistance training (RT) performed alone (19). Understanding practical factors influencing the interference to neuromuscular adaptations with concurrent training and strategies to monitor this interference effect are key to developing practical strategies to maximize adaptation to concurrent training.

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Countermovement jump (CMJ) testing has emerged as a valuable tool for monitoring changes in neuromuscular function with exercise training or fatigue (4). Performing CMJ testing on a force platform allows various kinetic and kinematic CMJ parameters to be derived, which are sensitive for detecting changes in neuromuscular function after both single training sessions (or match play) and longer-term training (or competition) periods (5,8,17). Modulation of kinetic and kinematic CMJ parameters can occur independently to changes in CMJ height, potentially reflecting an altered CMJ movement strategy mediated by residual neuromuscular fatigue (8). Analysis of changes in kinetic and kinematic CMJ parameters can therefore provide valuable information on changes in neuromuscular status, which may be overlooked when only assessing changes in CMJ height.

Since concurrent training influences changes in neuromuscular function relative to RT performed alone, it is plausible these changes may manifest as modulated CMJ performance. Although there is some evidence that concurrent training influences changes in CMJ performance relative to RT alone (2,3,14–16), often only CMJ height is assessed (1,2,12,15). Consequently, this approach limits insight into the influence of concurrent training on neuromuscular function manifesting as an altered CMJ movement strategy rather than CMJ outcome per se.

Whether any modulation of CMJ performance with concurrent training is associated with other neuromuscular parameters commonly used to assess the interference effect, such as 1RM strength, is also unclear. Although CMJ performance has been shown to be related to measures of dynamic maximal strength (14), this has not been examined in the context of training-induced changes in these parameters with concurrent training. Associations between changes in CMJ parameters and maximal strength gain (or interference to strength development) may highlight the utility of CMJ testing as a low-physiological strain tool for monitoring changes in neuromuscular status interference to neuromuscular adaptations with concurrent training.

This study aimed to build on previous work (7) to determine the influence of concurrent training (incorporating either high-intensity interval training [HIIT] or moderate-intensity continuous training [MICT]) on CMJ parameters, compared with RT alone. A secondary aim was to determine whether any evidence of impaired changes in neuromuscular function with concurrent training, gleaned from CMJ parameters, was associated with other neuromuscular adaptations (i.e., maximal strength gain).

Methods

Experimental Approach to the Problem

The study procedures were performed as described in Fyfe et al. (7). Briefly, subjects completed 8 weeks of RT either alone (RT group, $n = 8$) or combined with either HIIT cycling (HIIT + RT group, $n = 8$) or moderate-intensity continuous cycling (MICT + RT group, $n = 7$). Maximal strength and CMJ performance were assessed before (PRE), after 4 weeks of training (MID), and >72 hours (maximal strength) and >5–7 days (CMJ performance) after (POST) the training intervention.

Subjects

Twenty-three men (mean ± *SD*: age, 29.6 ± 5.5 years, range 20-35 years; height, 182.4 ± 5.9 cm; body mass, 84.9 ± 11.4 kg) recreationally performing endurance or resistance exercise at least twice per week completed the study. All subjects presented with no adverse cardiovascular or musculoskeletal risk factors. All subjects provided written informed consent and none were minors. All study procedures were approved by the Human Research Ethics Committee at Victoria University.

Procedures

Maximal Strength (1 Repetition Maximum) Testing. Maximal (1RM) leg press strength was assessed as previously described (7) using a 45° incline leg press (Hammer Strength Linear, Schiller Park, IL). Briefly, after a standardized warm-up (5 and 3 repetitions at 50 and 70% estimated 1RM, respectively), single repetitions of increasing load were attempted until the maximal load possible for 1 repetition was determined. Three minutes of recovery was allowed between 1RM attempts. Each leg press repetition began in full knee extension with the heel placed at the bottom edge of the foot plate and with a range of motion of 90° knee flexion/extension.

Countermovement Jump Testing. Countermovement jump performance was assessed as previously described (7) using a force plate (400 Series; Fitness Technology, Adelaide, Australia) sampling at 600 Hz. After a standardized warm-up (3 submaximal CMJs), 3 maximal CMJs were performed, interspersed with 1 minute of passive recovery. The average values of each variable from these 3 trials were used for analysis (4). Jumps began from a standing position, with the hands placed on the hips throughout. Subjects self-selected their jump depth and were instructed to aim for maximal jump height.

Training Intervention. All groups performed an identical, whole-body, RT program (3 days·wk^{-1}) progressing in intensity and volume from 3 sets of 12 repetitions (~65% 1RM) to 5 sets of 4 repetitions (~90% 1RM) (7). Concurrent training groups performed either HIIT (progressing from 5–11 × 2 minutes at 120–150% lactate threshold/1-minute passive recovery) or work-matched MICT (progressing from 15 to 33 minutes at 80–100% lactate threshold) 10 minutes before each RT session (7).

Statistical Analyses

For 3 subjects, data were unavailable for all CMJ variables at either PRE, MID, or POST; therefore, analyses were performed on 20 subjects ($n = 7$, 7, and 6 for RT, HIIT + RT, and MICT + RT, respectively). To reduce bias from nonuniformity of error, heteroscedastic data were log-transformed before analysis. Test-retest reliability (typical error as CV [%] ±90% confidence limits [CL]) of CMJ variables was determined between familiarization and PRE testing ($n = 10$). Countermovement jump data were analyzed using linear mixed models, with "time" (repeated measure), "group" and "group × time" as fixed factors, and "subject" as a random factor. The magnitude of change in CMJ variables was determined through Cohen's *d* (effect size, ES). Effects were considered meaningful if there was >75% probability of being positive relative to the smallest worthwhile change (ES = 0.2) and were deemed unclear if there was >5% probability of also being negative (10). Uncertainty of effects was determined as 90% CL and exact *p* values (unless $p < 0.001$). Linear mixed models were analyzed using SPSS Statistics Version 25 (IBM, Somers, NY), and ES and CL values were determined using custom Excel spreadsheets (11). Where any between-group differences for changes in CMJ variables were identified, relationships between these changes and strength gain were determined through linear regression (GraphPad Prism Version 7.02; GraphPad Software, La Jolla, CA).

Results

Reliability of Countermovement Jump–Derived Variables

Typical error values (CV [%] ± 90% CL) for each CMJ variable were relative peak force (4.4 ± 1.5%), relative peak power (4.7 ± 1.5%), total impulse (5.5 ± 1.5%), and flight time:contraction time ratio (FT:CT; 11.9 ± 1.5%).

Training-Induced Changes in Maximal Strength

Relative 1 Repetition Maximum Leg Press Strength. Raw data for relative 1RM leg press strength (expressed as mean values ± *SD*) for each group at PRE, MID, and POST are shown in Table 1. The PRE to POST change in relative 1RM leg press strength was impaired for both HIIT + RT (ES: −0.50; ±90% CL ± 0.64) and MICT + RT (ES: −0.51; ±0.47) vs. RT.

Table 1
Raw data for relative 1RM leg press strength all countermovement jump (CMJ)-derived measures obtained before (PRE), midway through (MID), and after (POST) the training intervention.*†

Training group	Relative 1RM leg press strength ($kg\cdot kg$ body mass^{-1}) PRE	MID	POST	Relative peak force ($N\cdot kg^{-1}$) PRE	MID	POST	Relative peak power ($W\cdot kg^{-1}$) PRE	MID	POST
RT only	3.5 ± 0.6	4.2 ± 0.6	4.9 ± 0.8	22.3 ± 2.5	22.8 ± 2.5	23.3 ± 2.2	38.4 ± 6.3	36.8 ± 5.7	38.0 ± 5.8
HIIT + RT	3.6 ± 0.4	4.1 ± 0.6	4.6 ± 0.6	21.9 ± 1.5	21.6 ± 1.1	21.7 ± 1.5	35.2 ± 2.9	34.6 ± 2.6	35.5 ± 3.6
MICT + RT	3.4 ± 0.6	3.9 ± 0.7	4.3 ± 0.5	20.2 ± 7.7	21.6 ± 1.9	18.2 ± 7.5	35.4 ± 4.2	33.7 ± 4.4	35.2 ± 4.6

Training group	Total impulse ($N\cdot s^{-1}$) PRE	MID	POST	Relative mean power ($W\cdot kg^{-1}$) PRE	MID	POST	Flight time:contraction time (s) PRE	MID	POST
RT only	1,117.5 ± 238.7	1,115.9 ± 217.5	1,061.4 ± 184.7	9.33 ± 3.3	7.38 ± 2.1	7.92 ± 2.2	0.55 ± 0.2	0.61 ± 0.1	0.64 ± 0.1
HIIT + RT	1,092.9 ± 143.3	1,098 ± 208.4	1,059 ± 182.1	7.46 ± 1.6	7.24 ± 0.7	8.02 ± 1.2	0.54 ± 0.1	0.56 ± 0.1	0.54 ± 0.1
MICT + RT	1,096.2 ± 164.3	1,174.4 ± 180.4	1,160.2 ± 245.6	8.02 ± 1.4	7.42 ± 1.5	7.53 ± 1.2	0.56 ± 0.1	0.56 ± 0.1	0.56 ± 0.1

*1RM = 1 repetition maximum; RT = resistance training; HIIT = high-intensity interval training; MICT = moderate-intensity continuous training.
†Data shown are mean values ± *SD*.

Training-Induced Changes in Countermovement Jump–Derived Variables

Raw data for all CMJ variables (expressed as mean values ± *SD*) for each group at PRE, MID, and POST are shown in Table 1. Training-induced changes in CMJ variables between PRE- and MID-intervention and PRE- and POST-intervention are presented in Figure 1A, B, respectively.

Relative Peak Force

There was a group × time interaction ($p = 0.036$) for relative peak force, which increased at POST for RT (ES: 0.43; ±0.37), and decreased at both MID (ES: −0.61; ±0.35) and POST (ES: −0.88; ±0.83) for MICT + RT. There was no substantial change for HIIT + RT at either MID (ES: −0.15; ±0.47) or POST (ES: 0.06; ±1.0).

Compared with RT, the PRE-MID change in relative peak force was impaired for both HIIT + RT (ES: −0.44; ±0.51) and MICT + RT (ES: −0.74; ±0.49) and for MICT + RT compared with HIIT + RT (ES: −0.46; ±0.64).

The PRE-POST change in relative peak force was also attenuated compared with RT for both HIIT + RT (ES: −0.72; ±0.61) and MICT + RT (ES: −1.25; ±0.63) and for MICT + RT vs. HIIT + RT (ES: −0.68; ±0.80).

Relative Peak Power and Total Impulse. Neither relative peak power (group × time interaction: $p = 0.946$) nor total impulse (group × time interaction: $p = 0.751$) was altered with training or differed between groups.

Relative Mean Power. There was no group × time interaction for relative mean power ($p = 0.524$), which decreased at MID for both RT (ES: −0.55; ±0.61) and MICT + RT (ES: −0.41; ±0.56), and was unchanged for HIIT + RT (ES: −0.06; ±0.54).

At POST, relative mean power was unchanged for RT (ES: −0.36; ±0.69) and MICT + RT (ES: −0.40; ±0.49) and increased for HIIT + RT (ES: 0.53; ±0.79).

The PRE-POST change in relative mean power was impaired for HIIT + RT compared with MICT + RT (ES: −0.68; ±0.79).

Flight Time:Contraction Time Ratio (FT:CT). There was no group × time interaction ($p = 0.371$) for the FT:CT, which increased from PRE-POST only for RT (ES: 0.53; ±0.39).

Compared with RT, changes in the FT:CT between both PRE-MID and PRE-POST were impaired for MICT + RT (ES: −0.38; ±0.42 and ES: −0.60; ±0.55, respectively) and impaired between PRE-POST for HIIT + RT (ES: −0.75; ±0.30).

Association Between Changes in Countermovement Jump–Derived Measures and Maximal (1 Repetition Maximum) Strength Gain

Since the training-induced changes in selected CMJ parameters were impaired after concurrent training compared with RT alone, we determined whether changes in CMJ parameters were related to other neuromuscular adaptations (i.e., maximal strength gain).

There were positive associations between the PRE-POST changes in relative 1RM leg press strength and both relative peak force ($r^2 = 0.26$; $p = 0.026$; Figure 2A) and the FT:CT ($r^2 = 0.19$; $p = 0.056$; Figure 2B). A summary of the relationships between changes in relative 1RM leg press strength and CMJ parameters between PRE-MID and PRE-POST is shown in Table 2.

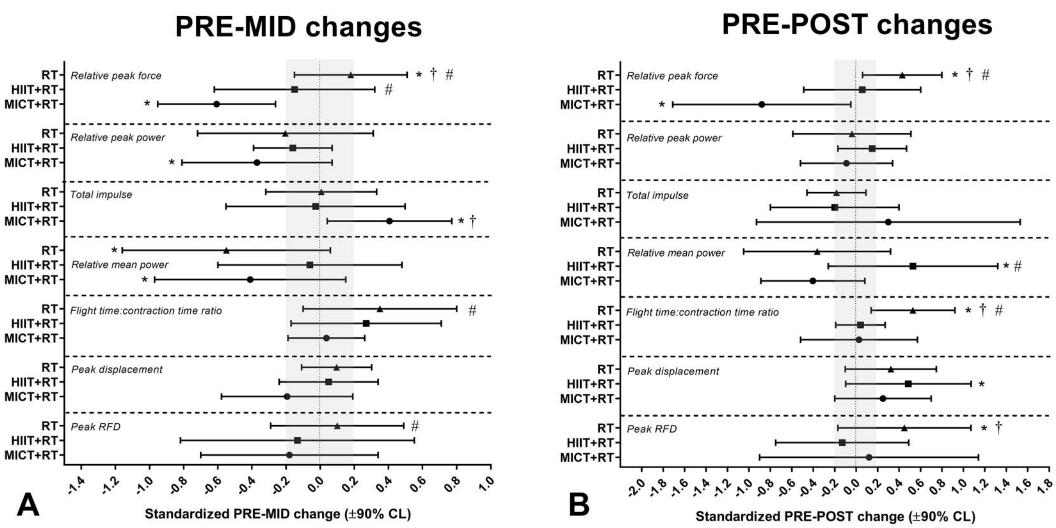

Figure 1. Within-group changes (Cohen's *d* effect sizes ±90% confidence limits) for all measured countermovement jump (CMJ) variables between PRE- and MID-intervention (A) and PRE- and POST-intervention (B). Shaded area indicates boundaries of the smallest worthwhile change (ES = 0.2). *Different vs. PRE; greater change (either PRE-MID or PRE-POST) vs. †HIIT + RT, §MICT + RT. RT = resistance training; MICT = moderate-intensity continuous training; HIIT = high-intensity interval training.

Discussion

The main findings of this study were that improvements in markers of neuromuscular function, including relative 1RM leg press strength and the CMJ parameters relative peak force and the FT:CT, were impaired with concurrent training relative to RT alone. Attenuated improvements in CMJ parameters were less evident in the first 4 weeks of training compared with the entire intervention (i.e., from PRE-MID vs. PRE-POST), suggesting interference to neuromuscular adaptations is exacerbated with longer periods of concurrent training. Training-induced changes in CMJ relative peak force and FT:CT were associated with relative 1RM leg press strength gain, suggesting these markers may be used to monitor changes in other neuromuscular parameters with concurrent training.

Taken together with the observations that neither total impulse nor peak CMJ displacement (7) was impaired with concurrent training, the attenuated improvements in time-related CMJ variables (i.e., relative peak force, the FT:CT, and peak RFD (7)) suggest concurrent training promoted an altered CMJ movement strategy, possibly attributed to accumulated neuromuscular fatigue during the training intervention. Such disruptions to CMJ force-time characteristics independent of overall CMJ output (i.e., peak displacement) have important implications for situations requiring rapid force production, which applies to most sport-specific tasks (e.g., jumping, sprinting, and changes of direction). These findings further highlight the pitfalls of only measuring jump height when implementing CMJ testing as a tool for monitoring changes in neuromuscular status. Although some concurrent training studies have only assessed changes in CMJ height (1,2,12,15), blunted improvements in other CMJ parameters, including peak force and peak power, have been shown relative to RT alone (3,16,18). Impaired CMJ performance in selected CMJ variables (including relative peak force) has also been observed in lacrosse athletes undertaking concurrent training, which was attributed to accumulated neuromuscular fatigue across the season (17). Our findings likewise potentially reflect accumulated neuromuscular fatigue imposed by individual endurance training sessions during the concurrent training intervention, culminating in the impaired neuromuscular adaptations observed.

Although improvements in both relative peak force and the FT:CT were impaired with concurrent training, this was not seen

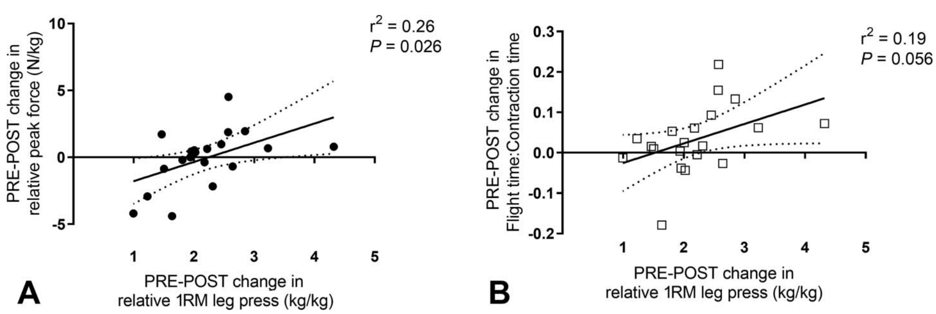

Figure 2. Associations between PRE-POST changes in relative 1RM leg press strength and CMJ-derived relative peak force (A) and the flight time:contraction time ratio (B). 1RM = 1 repetition maximum; CMJ = countermovement jump.

Table 2
Correlations between changes in relative 1RM leg press strength and CMJ parameters between PRE-MID and PRE-POST training.*

	PRE-MID changes		PRE-POST changes	
Δ 1RM leg press vs.	r^2	p	r^2	p
Δ Relative peak force	0.001	0.883	0.26	0.026
Δ Relative peak power	0.05	0.334	0.06	0.834
Δ Total impulse	0.008	0.714	0.001	0.352
Δ Relative mean power	0.01	0.665	0.002	0.821
Δ Flight time:contraction time	0.05	0.352	0.19	0.056

*1RM = 1 repetition maximum; CMJ = countermovement jump.

consistently across all CMJ variables measured. For example, both relative mean power and peak displacement were only increased from PRE to POST for HIIT + RT. However, since the changes in both relative mean power and peak displacement were not different for concurrent training vs. RT alone, it is unlikely these variables reflect differences in neuromuscular status between groups. Nevertheless, the CMJ variables impaired with concurrent training in this study (i.e., relative peak force and the FT:CT) have been previously linked to accumulated neuromuscular fatigue in both lacrosse (17) and Australian football (5) athletes, supporting the notion that the present findings also reflect accumulated neuromuscular fatigue.

There has been much interest in determining the role of practical factors, such as endurance training intensity, in mediating the interference effect with concurrent training. Previous work from the same training intervention as this study (7) showed similar interference to absolute 1RM leg press strength gain with concurrent training incorporating either HIIT or MICT, which is in agreement with the present findings for relative 1RM strength. It is therefore perhaps not surprising there were no differences in CMJ parameters between concurrent training groups from the same training intervention. Although these findings potentially suggest endurance training intensity plays little role in mediating interference to neuromuscular adaptations with concurrent training, a number of methodological factors must also be considered, particularly since neuromuscular fatigue is both task- and training status-dependent (13). For example, cycling and running likely impart divergent neuromuscular fatigue (13), potentially limiting applicability of these findings to running-based sports. The recovery time allowed between endurance and RT sessions must also be considered, with the 10-minute between-mode recovery period in this study likely suboptimal from a neuromuscular adaptation standpoint compared with longer between-mode recovery periods. Well-trained individuals may be less susceptible to neuromuscular fatigue compared with untrained individuals, so the present findings may also be less applicable to athletic populations.

In summary, improvements in CMJ-derived markers of neuromuscular function were impaired with concurrent training, which occurred independent of endurance training intensity. These impairments were less evident in the first 4 weeks of training, potentially indicating a worsening of interference to neuromuscular adaptations with longer concurrent training periods. Training-induced changes in CMJ relative peak force and the FT:CT were also positively associated with relative 1RM strength gain. Overall, these findings highlight the potential for CMJ testing to inform modulation of changes in neuromuscular function with concurrent training and to serve as a low-physiological strain alternative to maximal strength testing for monitoring the interference effect with concurrent training.

Practical Applications

These findings highlight the utility of certain CMJ-derived variables (i.e., peak force and the FT:CT) as markers of neuromuscular status and modulation of neuromuscular adaptations during concurrent training. Identification of suboptimal neuromuscular adaptation during concurrent training through CMJ testing could allow practitioners to adjust endurance training loads accordingly to prioritize strength development during certain training phases.

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