©Journal of Sports Science and Medicine (2017) **16**, 391-395
http://www.jssm.org

Research article

Moderate Intensity Cycling Exercise after Upper Extremity Resistance Training Interferes Response to Muscle Hypertrophy but Not Strength Gains

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Abstract
The purpose of the present study was to examine the effect of 30-min moderate intensity cycling exercise immediately after upper-body resistance training on the muscle hypertrophy and strength gain. Fourteen subjects were randomly divided between two groups. One group performed moderate intensity (55% of maximum oxygen consumption [VO_{2max}], 30 min) cycle training immediately after arm resistance training as concurrent training (CT; n = 7, age: 21.8 ± 0.7 years, height: 1.68 ± 0.06 m, weight: 60.3 ± 7.4 kg); the second group performed the same endurance and arm RT on separate days as control group (SEP; n=7, age: 22.1 ± 0.7 years, height: 1.76 ± 0.05 m, weight: 63.8 ± 3.6 kg). The supervised progressive RT program was designed to induce muscular hypertrophy (3-5 sets of 10 repetitions) with bilateral arm-curl exercise using 75% of the one repetition maximum (1RM) with 2-min rest intervals. The RT program was performed for 8 weeks, twice per week. Muscle cross-sectional area (CSA), 1RM, and VO_{2max} were measured pre- and post-training. Significant increases in muscle CSA from pre- to post-training were observed in both the SEP ($p = 0.001$, effect size [ES] = 0.84) and the CT groups ($p = 0.004$, ES = 0.45). A significant increase in 1RM from pre- to post-training was observed in the SEP ($p = 0.025$, ES = 0.91) and CT groups ($p = 0.001$, ES = 2.38). There were no interaction effects (time × group) for CSA, 1RM, or VO_{2max}. A significantly higher percentage change of CSA was observed in the SEP group (12.1 ± 4.9%) compared to the CT group (5.0 ± 2.7%, $p = 0.029$), but no significant difference was observed in the 1RM (SEP: 19.8 ± 16.8%, CT: 24.3 ± 11.1%). The data suggest that significant improvement of CSA and strength can be expected with progressive resistance training with subsequent endurance exercise performed immediately or on a different day. Changes in CSA might be affected by subsequent cycling exercise after 8 weeks of training.

Key words: Concurrent training; systemic; strength; muscle hypertrophy; arm-curl exercise.

Introduction

Previous studies reported that concurrent endurance and resistance training, compared to resistance training alone, leads to a reduction in muscular strength (Dolezal et al., 1998; Hickson, 1980; Kraemer et al., 1995), hypertrophy (Hickson, 1980; Kraemer et al., 1995), and power (Kraemer, Patton et al. 1995). The effects of concurrent training have been explained as the activity of selected negative regulators of protein synthesis, such as adenosine monophosphate-activated protein kinase (AMPK), which is increased by endurance exercise in an intensity-dependent manner (Bodine et al., 2001; Bolster et al., 2002; Rose et al., 2009). Based on molecular mechanisms, the effects of concurrent training should be observed when the same muscle is subjected to both resistance and endurance exercise. A meta-analysis reported that local interference with lower-body strength or muscle gain occurs when whole-body or lower-body resistance training and lower-body endurance training, such as running and cycling, are performed concurrently (Wilson et al., 2012).

Contemporaneous whole-body resistance training and lower-body endurance training have also been examined (Dolezal and Potteiger, 1998; Kraemer et al., 1995; Robineau et al., 2016). Dolezal et al. (1998) examined 8 weeks of concurrent whole-body resistance training and cycling endurance training and showed that change in bench press strength gain (12%) was less than that with resistance training alone (24%). Although significant differences were not observed between the groups, there is a possibility that concurrent interference could have occurred even with different muscle groups exercised in strength versus endurance training. Robineau et al. (2016) evaluated whether the duration (0, 6, or 24 hours) of recovery between strength and endurance training influences the response to concurrent training. They suggested that 0- and 6-hour recovery periods in concurrent training produces lower adaptation of upper- and lower-body strength and muscle hypertrophy compared to strength training only over a 7-week period. This evidence suggests that systemic interference might occur if different muscles are exercised in strength and endurance training.

In our previous study, several possible mechanisms were discussed concerning systemic interference with upper-body strength and muscle gain after concurrent upper-body resistance training and lower-body endurance exercise. One possible mechanism involves blood redistribution due to aerobic leg exercise (Kagaya et al., 1997). Previous studies suggested that permanently high levels of creatine (Cr) in trained muscle increase AMP-activated protein kinase (AMPK) activity (Ponticos et al., 1998). If the blood flow is concentrated in the exercising leg muscles due to blood redistribution, slow recovery of increased Cr after arm resistance training might activate AMPK in the targeted arm muscle. AMPK signaling is activated during medium (60% maximal oxygen consumption [VO_{2max}]) and high (80% VO_{2max}) intensity endurance training, but not during low (40% VO_{2max}) intensity exercise (Chen et al., 2003). Since blood redistribution also occurs in long-lasting exercise, moderate intensity (55% VO_{2max}), long duration (30 min) cycling

Received: 19 April 2017 / Accepted: 06 July 2017 / Published (online): 01 September 2017

subsequent to arm strength training might also interfere with arm muscle hypertrophy and strength gain.

The purpose of this study was to examine whether moderate intensity (55% VO_{2max}, 30 min) cycling exercise subsequent to upper-body strength training influences the training response of muscle hypertrophy and strength. We hypothesized that moderate intensity endurance exercise subsequent to strength training systemically interferes with muscle hypertrophy and strength.

Methods

Subjects

Fourteen Japanese men (age: 22.0 ± 0.7 years, height: 1.72 ± 0.05 m, weight: 62.1 ± 5.8 kg, arm-curl 1RM: 22.3 ± 3.0 kg) volunteered to participate in this study. Subjects were randomly assigned to two groups. One group performed moderate intensity endurance training immediately after resistance training as concurrent training group (CT group, n = 7) and the second group performed moderate intensity endurance training and resistance training on separate days as control group (SEP group, n = 7) (Figure 1). Muscle CSA, 75% one repetition maximum (1RM), and VO_{2max} were measured pre- and post-training. All participants were informed of the potential risks of the experiment and provided written consent to participate. The study was approved by the ethics committee of Nippon Sport Science University and was performed in accordance with the Declaration of Helsinki for Human Research.

Training protocol

A supervised progressive resistance training program was designed to induce muscular hypertrophy (week 1-2: 3 sets of 10 repetitions (reps), week 3-4: 4 sets of 10 reps, and week 5-8: 5 sets of 10 reps at 75% 1RM of bilateral arm-curl exercise with 2-min rest intervals). This program was performed using an arm-curl machine (Hammer strength plate-loaded seated biceps, Life fitness, Chicago, USA) for 8 weeks, with training carried out twice per week at least 24 hours apart (Fig. 1). A warm-up set of 8-10 repetitions was performed at 50% of the individual's measured 1RM. Each session was completed to the set and repetition prescribed for that week, however, each final set was performed to failure. The training intensity was increased by 5% of the subject's baseline 1RM if they completed two additional repetitions (2 reps) for a given work set during their final working set. All subjects performed 30-min moderate intensity endurance training at 55% load (W) of VO_{2max} using a cycle ergometer immediately after 30 min of the resistance training protocol (CT) or on separate days at least 24 hours apart (SEP).

One repetition maximum

All subjects performed the test of 1RM using an arm-curl machine (Kikuchi et al., 2015). Before the test, subjects were given instructions on proper technique and test procedures. After a warm-up consisting of several sets of 6 to 10 repetitions using a light load, each participant attempted a single repetition with a load believed to be approximately 90% of his maximum. If the attempt was successful, weight was added, depending on the ease with which the single repetition was completed. If the attempt was not successful, weight was removed from the bar, and the exercise was repeated. A minimum of 3 min rest was allowed between maximal attempts. This procedure continued until the participant was not able to complete a single repetition through the full range of motion. A subject's 1RM was determined when the exercise could be performed with proper form using the heaviest load, and was usually achieved in 3 to 5 attempts.

Muscle cross-sectional area

Using a 0.3 T magnetic resonance (MR) system AIRIS II (HITACHI Tokyo, Japan), the CSAs of the elbow flexion muscles were calculated using T1-weighted cross-sectional images of the upper arm at 50% area between the lateral epicondyle of the humerus and the acromion process of the scapula (spin echo method; repetition time, 700 ms; echo time, 20 ms; slice thickness and slice space, 10 mm). Among the 3 slices (50% of upper arm, 10 mm distal and proximal), the same investigator calculated the muscle CSA of the biceps brachii and the brachialis twice; the mean value was used for calculations. The CSA of each muscle was traced and calculated by Image J computer software (National Institutes of Health, Bethesda, MD, USA).

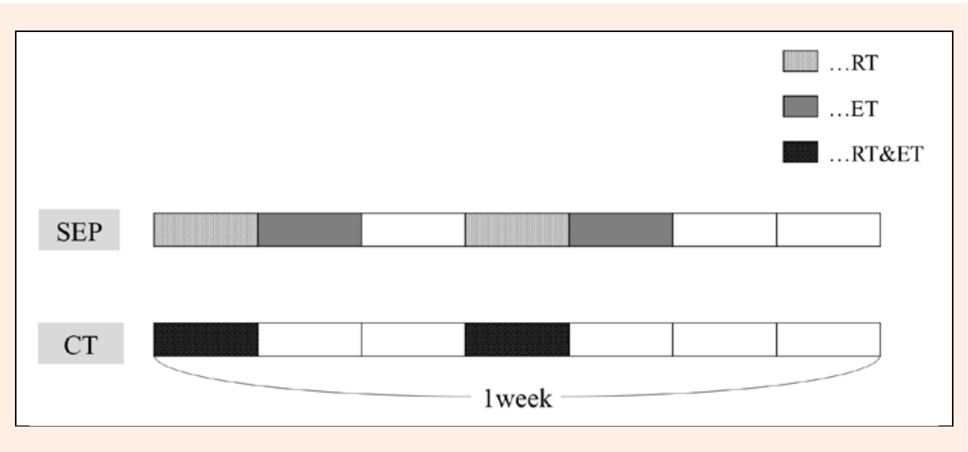

Figure 1. Concurrent training protocols. RT, resistance training; ET, endurance training; SEP, concurrent endurance and resistance training on separate days; CT, endurance training immediately after resistance training .

Table 1. Effect on VO_2max, CSA, 1RM, and body weight of 8 weeks of concurrent endurance and resistance training on separate day (n = 7) and endurance training immediately after resistance training (n = 7). Values are mean (±SD).

Parameter tested	Training Condition	Pre-Treatment	Post-Treatment	P value	ES (95%CI)
VO_{2max}(ml/kg/min)	SEP	46.1 (14.2	49.5 (13.8)	.661	0.24 (-0.83-1.28)
	CT	46.8 (12.)5	47.1 (11.0)	.964	0.03 (-1.02-1.07)
CSA(cm^2) †	SEP	8.8 (1.1)	9.9 (1.5)	**.001****	0.84 (-0.31-1.86)
	CT	9.7 (1.0)	10.2 (1.2)	**.004****	0.45 (-0.64-1.48)
1RM(kg) †	SEP	21.6 (3.9)	25.6 (4.8)	**.025***	0.91 (-0.24-1.94)
	CT	23.1 (1.8)	28.7 (2.8)	**.001****	2.38 (0.88-3.54)
Weight (kg)	SEP	60.3 (7.4)	60.6 (8.2)	.661	0.08 (-0.98-1.12)
	CT	63.8 (3.6)	63.8 (3.9)	.918	0.00 (-1.05-1.05)

SEP, concurrent endurance and resistance training on separate day; CT, endurance training immediately after resistance training; VO2max, maximal oxygen consumption; CSA, Cross-sectional area of muscle; 1RM, 1 repetition maximum; ES, Effect size; 95%CI; 95% confidence interval. †p < 0.05 significant main effect (time) by 2-way ANOVA. * p < 0.05, ** p < 0.01 significant difference after training by Bonferroni post-hoc test

VO_{2max}

A maximal graded exercise test was performed on a cycle ergometer (PowerMaxV II, Combi, Tokyo, Japan) to measure VO_{2max}. After a warm-up consisting of 3-5 min using light resistance on the cycle ergometer during which they strived to achieve a Borg's rating of perceived exertion of 13–14, subjects began the test at 60 W with an increase of 20 W every minute thereafter using the ramp method. Pedaling rate was maintained between 55 and 65 rpm throughout the test. Expired gases and hart rate were collected and analyzed using the AE100i (Minato, Tokyo, Japan) system and HR monitor (V800, Polar, Tampere, Finland). VO_{2max} was determined if at least 2 of the following criteria were met: (a) peak respiratory exchange ratio was above 1.10, (b) measured HRmax was within 10 beat•min^{-1} of age-predicted HRmax, and, (c) it was observed a plateau in VO_2.

Statistical analysis

Values are represented as mean ± standard deviation (SD). The SPSS statistical package, version 22.0 for Macintosh, was used to perform all statistical evaluations. A two-way analysis of variance (ANOVA) (groups × time) with repeated measures was performed to assess training-related differences in the CT and SEP groups for each dependent variable. In addition, Bonferroni's post-hoc test was performed to evaluate training-related changes within groups. Cohen's d effect sizes, reported for all observations with ≤ 0.20 representing a small effect, 0.50 representing a medium effect, and ≥ 0.80 representing a large effect (Cohen 1988), were estimated to compare the magnitude of training response. The level of significance was set at $p < 0.05$.

Results

Table 1 shows pre- and post-training VO_{2max}, CSA, and 1RM. At baseline, no significant differences were observed between groups and no interaction effect was observed for any of the parameters. In addition, the main effect (time) was observed in CSA and 1RM using 2-way ANOVA. Significant increases in CSA from pre- to post-training were observed in the SEP group (p = 0.001, effect size [ES] = 0.84, 95% CI -0.31 to 1.86) and the CT group (p = 0.004, ES = 0.45, 95% CI -0.64 to 1.48). Significant increases in 1RM from pre- to post-training were observed in the SEP group (p = 0.025, ES = 0.91, 95% CI -0.24 to 1.94) and the CT group (p = 0.001, ES = 2.38, 95% CI 0.88 to 3.54). There was no significant change in VO_{2max} and body weight from pre- to post-training in either group.

A higher percent change of CSA was observed in the SEP group (12.1 ± 4.9%) compared to the CT group (5.0 ± 2.7%, p = 0.029), but no significant difference was observed in the 1RM (SEP: 19.8 ± 16.8%, CT: 24.3 ± 11.1%).

Discussion

The present study examined whether moderate intensity leg exercise immediately after resistance training influences the arm training response of muscle strength and hypertrophy. We hypothesized that moderate intensity (55% VO_{2max}) long duration (30 min) cycle exercise subsequent to arm resistance training would interfere with arm muscle hypertrophy and strength. Results indicate that the main effect (time) was observed in increases of CSA and 1RM using 2-way ANOVA. In addition, no interaction effect was observed in any of the measured parameters. However, significantly higher increases in the magnitude of CSA changes were observed in the SEP group compared with the CT group. In addition, the SEP group had higher effect size of CSA increases than the CT group (0.84 vs. 0.45). No statistically significant VO_{2max} improvement occurred after 8 weeks of concurrent training with 30 min of moderate intensity cycling at 55% VO_{2max} in either group. Interestingly, there was no statistically significant difference in the % change in 1RM between groups, but there was a substantial difference in the effect sizes between groups (SEP, 0.91 vs. CT, 2.38).

Our results showed that statistically significant increases of muscle CSA (12.1% vs. 5.0%) and strength (19.8% vs. 24.3%) were observed in the SEP versus CT groups, respectively. A recent review indicated that interference effects of concurrent training are associated with training variants such as exercise modality, frequency, and duration of endurance training (Wilson, Marin et al., 2012). This review also reported that, even if interference was observed, concurrent resistance and endurance training induced statistically significant muscle hypertrophy, strength, and power. Wilson et al. (2012) also reported that concurrent resistance and endurance training on the same day resulted in reduced effect size of muscle hypertrophy (0.80 vs. 1.06), strength (1.28 vs. 1.36), and power (0.36 vs. 0.47) compared to concurrent resistance and endurance training performed on separate days. Cantrell et al. (2014) examined the chronic effect on muscle strength and hypertrophy of concurrent strength and sprint interval training on separate days. Thus, our data and previous studies (Wilson et al., 2012; Cantrell et al., 2014) may suggest that endurance training, regardless of exercise intensity and muscles trained, does not impair anabolic adaptation to resistance training, if concurrent strength and endurance training are carried out on separate days. Future study is necessary to confirm the effects of different intensities on concurrent interference.

In the present study, a 12.1% change of muscle CSA was observed in the SEP group after an 8-week training session. The percent change of CSA in the SEP group was similar to that previously reported for 8-week training periods in the Japanese population (Kikuchi et al., 2015). In contrast, the change rate of 5.0% in the CT group was significantly smaller than that of the SEP group. Since the change rate of the SEP group is comparable to usual muscle hypertrophy seen with 8-week resistance training, the smaller change in the CT group suggests that concomitant leg exercise interfered with upper-body resistance training, although statistically significant muscle hypertrophy and strength gain was induced. Our previous study (Kikuchi et al., 2015) showed that sprint cycling interval training subsequent to upper-body strength training (arm-curl) was associated with systemic interference of muscle hypertrophy and strength gain. There is a strong possibility that aerobic leg cycling training subsequent to arm resistance training systemically interferes with muscle hypertrophy induced by arm resistance training.

In the present study, the data again indicate that systemic interference was observed even when the exercise consisted of moderate intensity (55% VO_{2max}), long duration (30 min) cycling training immediately after upper-body strength training; however, duration and frequency of endurance training in the present study seemed to be low for VO_{2max} improvement (Swain et al., 2002). These results might depend on a higher magnitude of blood flow redistribution in moderate intensity continuous exercise, such as 30 min, compared with the short duration of repeated sprint exercise, even when post-exercise oxygen consumption is included. Previously, we hypothesized that phosphocreatine (PCr) recovery in strength-trained muscle was retarded due to blood redistribution for subsequent leg exercise. Increased blood flow in arm muscles is important not only for early recovery of PCr but also for muscle development after strength training (Stebbings et al., 2013). Blood flow might be decreased in the arm during lower extremity exercise due to redistribution (Kagaya and Homma, 1997). Therefore, it is reasonable to consider that the recovery of PCr concentration after resistance training in upper-body muscles might not be sufficiently achieved when lower-body endurance exercise is performed immediately afterward.

Alternatively, chronic adaptation of the cardiovascular system for aerobic training might be due to different mechanisms. Pogliaghi et al. (2006) reported that 12-week leg cycling training in healthy elderly subjects significantly elevated VO_{2peak} of arm cranking exercise and vice versa. The same cross-transfer effects in young men were also reported by others (Tordi et al., 2001). These authors discussed cardiovascular adaptation, especially in central, which may contribute to the transfer effect. A recent meta-analysis also demonstrated that low to moderate intensity endurance exercise acutely and chronically decreases blood pressure and arterial stiffness after exercise (Vaitkevicius et al., 1993). Furthermore, aerobic exercise subsequent to resistance training has acute and chronic effects on blood pressure and arterial stiffness (Okamoto et al., 2007). These lines of evidence suggest that, in the resting state, improving cardiovascular function with leg endurance training might enhance local blood circulation in strength-trained arm muscles. Since blood supply is beneficial for muscle hypertrophy (Stebbings et al., 2013), whether chronic changes in baseline circulation have an effect on systemic interference during endurance and strength training should be considered.

The present study has several limitations. The sample size was small. As a result, the chance of a type II error occurring might be high. Second, we did not include a control group or strength training only group. Both groups are necessary to clearly investigate systemic interference in concurrent resistance training and endurance training. Lastly, the exercise protocol (arm-curl exercise) was minimal. It could be assumed that greater interference would be found when higher volume protocols are employed, particularly involving large, multi-joint movements. In present study, there was no statistically significant difference in the % change in 1RM between groups, but there was a substantial difference in the effect sizes between groups (SEP, 0.91 vs. CT, 2.38). It was in conflict with previous study using concurrent resistance training and moderate to high intensity endurance training (Wilson, Marin et al. 2012). Future study is necessary to confirm the effects of low to moderate intensity endurance training on concurrent interference for strength gains.

Conclusion

The data suggest that no interaction effect was observed in any of the outcome measures. However, moderate intensity cycling exercise immediately after upper-body resistance training influences the magnitude of muscle hypertrophy and relative value of CSA changes due to systemic factors; this effect was not observed if cycling and resistance training were performed on separate days. These results suggest that timing of endurance training could alter the degree of muscular growth induced by resistance training.

Acknowledgements

The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

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Key points

- Moderate intensity cycling exercise immediately after upper-body resistance training influences the magnitude of muscle hypertrophy and relative value of CSA changes.
- There was no statistically significant difference in the % change in 1RM between groups after concurrent strength training and moderate intensity endurance training.
- Timing of endurance training could alter the degree of muscular growth induced by resistance training.

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