The Effect of High-Intensity Interval Cycling Sprints Subsequent to Arm-Curl Exercise on Upper-Body Muscle Strength and Hypertrophy

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Abstract

Kikuchi, N, Yoshida, S, Okuyama, M, and Nakazato, K. The effect of high-intensity interval cycling sprints subsequent to arm-curl exercise on upper-body muscle strength and hypertrophy. *J Strength Cond Res* 30(8): 2318–2323, 2016—The purpose of this study was to examine whether lower limb sprint interval training (SIT) after arm resistance training (RT) influences training response of arm muscle strength and hypertrophy. Twenty men participated in this study. We divided subjects into RT group ($n = 6$) and concurrent training group (CT, $n = 6$). The RT program was designed to induce muscular hypertrophy (3 sets × 10 repetitions [reps] at 80% 1 repetition maximum [1RM] of arm-curl exercise) and was performed in an 8-week training schedule performed 3 times per week on nonconsecutive days. Subjects assigned to the CT group performed identical protocols as strength training and modified SIT (4 sets of 30-s maximal effort, separated in 4 m 30-s rest intervals) on the same day. Pretest and posttest maximal oxygen consumption ($\dot{V}O_2max$), muscle cross-sectional area (CSA), and 1RM were measured. Significant increase in $\dot{V}O_2max$ from pretest to posttest was observed in the CT group ($p = 0.010$, effect size [ES] = 1.84) but not in the RT group ($p = 0.559$, ES = 0.35). Significant increase in CSA from pretest to posttest was observed in the RT group ($p = 0.030$, ES = 1.49) but not in the CT group ($p = 0.110$, ES = 1.01). Significant increase in 1RM from pretest to posttest was observed in the RT group ($p = 0.021$, ES = 1.57) but not in the CT group ($p = 0.065$, ES = 1.19). In conclusion, our data indicate that concurrent lower limb SIT interferes with arm muscle hypertrophy and strength.

Key Words concurrent training, endurance, sprint interval training, systemic effects

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30(8)/2318–2323

Journal of Strength and Conditioning Research

Introduction

The concomitant integration of resistance and endurance training is termed concurrent training (CT). Many sports require the improvement of muscular strength, power, and size, and endurance simultaneously for success. However, previous studies reported that CT relative to resistance training (RT) alone resulted in decrement in strength (7,11,14), hypertrophy (11,14), and power (14).

A recent review indicated that interference effects of CT are associated with training variants such as exercise modality, frequency, and duration of the endurance training (21). Jones et al. (12) reported the effect of differing ratios of time spent in each strength and endurance exercise modality per session on adaptation of muscle strength and hypertrophy. The results suggested that a protocol of an endurance and strength training (ST) ratio of 3:1 increased the magnitude of the interference response on strength and hypertrophy compared with a protocol of ST only, or an endurance and ST ratio of 1:1, after 3 times per week for 6 weeks. Their findings indicate that the ratio of endurance to ST performed during CT influences the degree of interference. Therefore, maintaining the volume and duration of endurance training is important if the primary focus of the training intervention is improving strength and hypertrophy.

Previous studies for investigating CT have implemented continuous or interval endurance training before or subsequent to ST. Recently, many studies suggested that high-intensity endurance exercise, specifically sprint interval training (SIT), results in similar adaptations as low-intensity, high-volume endurance training (4,9). These studies demonstrated significant improvements in peak oxygen uptake at a substantially less training volume. In fact, the weekly training volume for SIT was ~90% lower than that for the continuous endurance training group (i.e., 225 vs. 2,250 kJ) (4). Therefore, in addition to similar physiological adaptations, SIT may be an optimal complement to ST in a CT program. Recently, Cantrell et al. (5) suggested that separate days of concurrent strength and SIT, such as ST, will not interfere with muscle hypertrophy and strength. To our knowledge, no data exist which examine chronic physiological adaptations (i.e., muscle cross-sectional area [CSA] and 1 repetition maximum [1RM]) to the same day protocol of concurrent sprint interval and ST.

In addition, it is well known that a cross-transfer effect (20), which provides increased exercise performance during exercise with the untrained limbs or parts, exists in strength and aerobic exercises. Pogliaghi et al. (16) evaluated the effect of upper-body endurance training (arm cranking) and low-body endurance training (cycling training) for 12 weeks on maximal and submaximal exercise capacity of each untrained limb in elderly subjects. They reported a significant effect of arm cranking and cycling training on both peak and submaximal untrained limb performance, which increased by 10% of pretraining values in each group (13). These results suggest that nonspecific improvement of aerobic capacity occurs independent of which muscle is exercised. In a practical sense, it is usual that arm ST and aerobic bike training are performed in a same training session. Thus, we wished to know whether ST performed in one body part is affected by aerobic training performed in another part.

Previous studies evaluated concurrent lower-body ST and lower-body endurance training (10,15), or concurrent whole-body ST and lower-body endurance training (7,12). Dolezal and Potteiger (7) reported concurrent interference as follows: eight weeks of concurrent whole-body ST and lower-body endurance training were observed to lower the percent change of 1RM bench press (12%) compared with the ST only group (24%). Dolezal and Potteiger (7) suggest that the cross-transfer effect (20) increases exercise performance during exercise with the untrained limbs and should be considered as one of the causes of concurrent interference.

The purpose of this study was to examine whether high-intensity interval cycling sprints and subsequent upper-body ST influence training response of muscle strength and hypertrophy. We hypothesized that SIT, which is lower in total volume than that of traditional endurance training, subsequent to ST, does not interfere with muscle hypertrophy and strength. We also tested whether sprint training performed with the lower limbs influenced arm ST by the cross-transfer effect (20).

Methods

Experimental Approach to the Problem

Subjects were randomly assigned to the experimental group: concurrent resistance and sprint interval group (CT) and RT alone group. A supervised progressive RT program designed to induce muscular hypertrophy (3 sets of 10 repetitions [reps] at 80% 1RM of bilateral arm-curl exercise) was performed in 8 weeks, with training performed 3 times per week on nonconsecutive days. Subjects assigned to the CT group performed protocols identical to the ST and modified SIT group, with 4 sets of 30-s maximum sprint, on the same day. One repetition maximum, muscle CSA, and maximal oxygen consumption ($\dot{V}O_2max$) were measured pretraining and posttraining in both groups. All testing and training were supervised by a National Strength and Conditioning Association, Certified Strength and Conditioning Specialist (NSCA–CSCS).

Subjects

Fourteen Japanese male subjects (age, 20 ± 1.8 years; age range, 18 to 22 years; height, 171.2 ± 4.9 cm; weight, 64.5 ± 4.7) volunteered to participate in this study. All participants had previous experience in weight training. Two subjects did not complete all training sessions, providing no explanation. None of the subjects was taking any medication. All the participants were informed about the potential risks of the experiment and gave their written consent to participate in the experiment. The study was approved by the ethics committee of Nippon Sport Science University and was in accordance with the Declaration of Helsinki for Human Research.

Procedures

Training Protocol. ***Resistance Training Group.*** A supervised progressive RT program designed to induce muscular hypertrophy (3 sets of 10 reps at 80% 1RM of bilateral arm-curl exercise, separated 90-second rest intervals) was performed for 8 weeks using arm-curl machine, with training performed 3 times per week on nonconsecutive days (Figure 1). A warm-up set of 8–10 repetitions was performed at 50% of the individual's measured maximum. The subjects perform to failure in the final set. The subjects perform to the training intensity was increased 5% over baseline 1RM if the final working set exceeded 12 repetitions in a given workout. All subjects were individually supervised by experienced instructors during each training session to reduce deviations from the study protocol and to ensure subject safety.

Concurrent Training Group. The SIT was performed in 4 sets of 30-s maximal effort, separated in 4 m 30-s rest intervals, on a PowerMaxV II (Combi, Tokyo, Japan) using a resistance equal to 7.5% of the subject's body weight. Each subject was then given a 3–5 minutes of warm-up period on a cycle ergometer, whereby they strived to achieve a warm-up heart rate of 130–140 $b \cdot min^{-1}$. Subjects assigned to the CT group performed protocols identical to the ST and modified SIT group, on the same day.

One Repetition Maximum. All subjects performed the test of 1RM using the arm-curl machine. Before the test, subjects were given instructions on proper techniques and test procedures. After a warm-up consisting of several sets of 6–10 repetitions using a light load, each participant attempted a single repetition with a load believed to be approximately 90% of his/her 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.

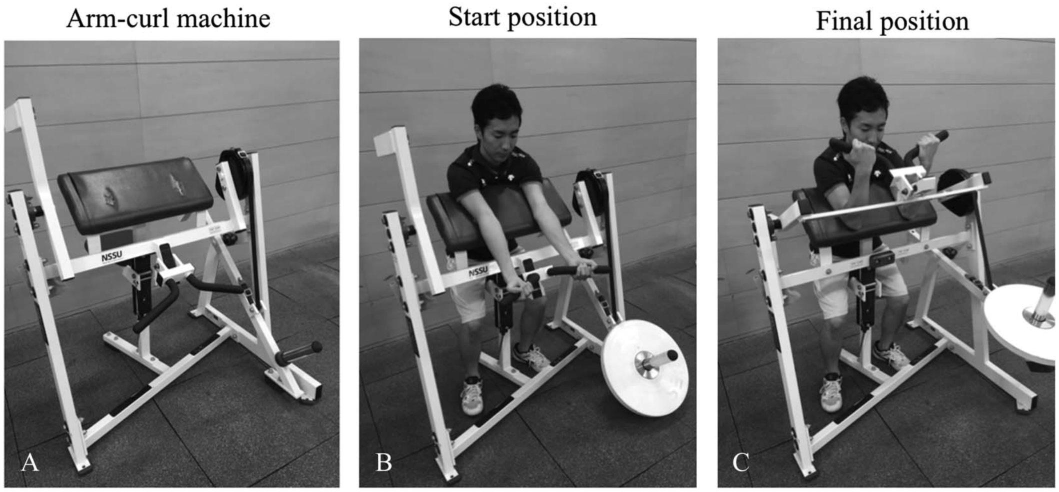

Figure 1. The arm-curl machine used in this study (A), the starting position of arm-curl exercise (B), and final position (C).

A minimum of 3 minutes of 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 considered when the exercise could be performed in proper form using the heaviest load and was usually achieved in 3–5 attempts.

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

$\dot{V}O_2max$. A maximal graded exercise test was performed on a cycle ergometer (PowerMaxV II; Combi) to measure $\dot{V}O_2$max. After a warm-up consisting of several minutes using light resistance, subjects began the test at 100 W with an

Table 1. Effect on $\dot{V}O_2$max, CSA, 1RM, and body weight of 8 weeks of concurrent training ($n = 6$) and resistance training alone ($n = 6$).*†

Parameter tested	Training Condition	Pretreatment	Posttreatment	p	ES (95% CI)
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})‡	CT	51.3 ± 6.3	63.0 ± 6.4	0.010§	1.84 (0.38 to 3.02)
	RT	51.8 ± 5.9	54.7 ± 10.0	0.559	0.35 (−0.81 to 1.47)
CSA (cm^2)	CT	13.6 ± 1.4	16.3 ± 3.5	0.110	1.01 (−0.26 to 2.13)
	RT	14.2 ± 2.0	16.6 ± 1.1	**0.030**§	1.49 (0.11 to 2.63)
1RM (kg)‖	CT	19.2 ± 5.6	27.5 ± 8.1	0.065	1.19 (−0.11 to 2.31)
	RT	21.7 ± 4.1	29.6 ± 5.8	**0.021**	1.57 (0.18 to 2.72)
Body weight (kg)	CT	63.3 ± 4.1	63.3 ± 2.1	0.993	0.00 (−1.13 to 1.13)
	RT	65.6 ± 5.4	65.0 ± 6.3	0.866	−0.10 (−1.24 to 1.04)

*$\dot{V}O_2$max = maximal oxygen consumption; CSA = cross-sectional area of muscle; 1RM = 1 repetition maximum; ES = effect size; 95% CI = 95% confidence interval; CT = concurrent training; RT = resistance training.
†Values are mean ± *SD*.
‡$p \leq 0.05$ significant interaction effect by 2-way analysis of variance (ANOVA).
§$p \leq 0.05$ significant difference after training by Bonferroni post hoc test.
‖$p \leq 0.05$ significant main effect (time) by 2-way ANOVA.

Table 2. Individual training response of $\dot{V}O_2$, CSA, and 1RM in CT and RT group.*

	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)		CSA (cm^2)		1RM (kg)	
Training Condition	Pre	Post	Pre	Post	Pre	Post
Subject A						
CT	49.6	62.3	14.3	17.5	15.0	25.0
Subject B						
CT	57.2	69.4	15.7	22.2	20.0	30.0
Subject C						
CT	52.3	61.3	13.4	13.8	15.0	25.0
Subject D						
CT	46.8	61.3	13.3	16.8	17.5	22.5
Subject E						
CT	59.2	70.6	11.4	11.4	17.5	20.0
Subject F						
CT	42.6	52.9	13.8	12.4	30.0	42.5
Subject G						
RT	48.0	51.1	17.3	17.2	20.0	30.0
Subject H						
RT	55.5	63.1	11.9	16.2	20.0	30.0
Subject I						
RT	60.5	66.3	12.4	17.5	20.0	27.5
Subject J						
RT	54.0	60.0	13.5	15.5	20.0	28.0
Subject K						
RT	48.8	41.3	15.6	16.5	20.0	22.5
Subject L						
RT	44.1	46.3	14.7	15.8	30.0	40.0

*$\dot{V}O_2max$ = maximal oxygen consumption; CSA = cross-sectional area of muscle; 1RM = 1 repetition maximum; CT = concurrent training; RT = resistance training.

increase of 20 W every minute thereafter. Pedaling rate was maintained between 55 and 65 RPM throughout the test. Expired gases were collected and analyzed by AE100i (Minato, Tokyo, Japan).

Statistical Analyses

The SPSS statistical package, version 22.0 for mac, was used to perform all the statistical evaluations. A two-way analysis of variance (ANOVA) (group vs. time) with repeated measures was performed to assess training-related differences in the ST and CT groups for each dependent variable. In addition, the Bonferroni post hoc test was performed to evaluate training-related changes within groups. Cohen's d effect sizes (ES), reported for all observations, with ≤ 0.20 representing a small effect, 0.50 representing a medium effect, and ≥ 0.80 representing a large effect (6), were estimated to compare with the magnitude of the training response. The level of significance was set at $p \leq 0.05$.

Results

Of the 14 subjects enrolled in the study, 12 successfully finished and were included in the analyses. Pretest and posttest $\dot{V}O_2max$, CSA, and 1RM are shown in Tables 1 and 2. No differences were observed between groups in all parameters at baseline. An interaction effect was observed in $\dot{V}O_2max$ ($p = 0.001$) but not in CSA and 1RM. In addition, a significant Mein effect (Time) was observed in only 1RM using a 2-way ANOVA. Significant increase in $\dot{V}O_2max$ from pretest to posttest was observed in the CT group ($p = 0.010$, ES = 1.84, 95% confidence interval [CI]: 0.38–3.02) but not in the RT group ($p = 0.559$, ES = 0.35, 95% CI: −0.81 to 1.47). Significant increase in CSA from pretest to posttest was observed in the RT group ($p = 0.030$, ES = 1.49, 95% CI: 011–2.63) but not in the CT group ($p = 0.110$, ES = 1.01, 95% CI: −0.26 to 2.13). Significant increase in 1RM from pretest to posttest was observed in the RT group ($p = 0.021$, ES = 1.57, 95% CI: 0.18–2.72) but not in the CT groups ($p = 0.065$, ES = 1.19, 95% CI: −0.11 to 2.31). There was no significant change of body weight from pretest to posttest in both groups.

Discussion

This study examined whether high-intensity interval cycling sprints before upper-body RT influences the training response of muscle strength and hypertrophy. We hypothesized that high-intensity and low-volume interval cycling sprint compared with traditional endurance training (9) subsequent to ST does not interfere with muscle hypertrophy and strength. However, our data might indicate that concurrent upper-body ST and sprint interval cycling sprints on the same day interfere with muscle hypertrophy and strength caused by systemic factors.

Previous research demonstrated that CT, relative to RT only, results in compromised strength (7,11,14), hypertrophy (14), and power development (14). Conversely, RT seems to have little to no negative impact on endurance performance and $\dot{V}O_2$max (21). In addition, Silva et al. (19) reported that CT performed twice a week promotes similar neuromuscular adaptations to ST alone and to concurrent strength combined with one of three types of aerobic training (continuous running, continuous cycling, and interval running) in young women. Our results were in agreement with these previous studies but against our hypothesis.

As a potential mechanism for local factors causing concurrent interference, the activity of selected negative regulators of protein synthesis, such as AMP-activated protein kinase (AMPK) and eukaryotic translation initiation factor-4E-binding protein 1 (4E-BP1), is increased by endurance exercise in an intensity-dependent manner (18). Moreover, previous studies suggest that AMPK activation has a significant inhibitory effect on mammalian target of rapamycin complex 1 (mTORC1) and its downstream signaling targets, thereby negatively regulating protein synthesis and hypertrophy (2,3). Recently, high-intensity interval training has been reported as a potent exercise strategy for inducing signaling related to mitochondrial biogenesis, with associated health benefits and athletic performance (8). Taken together, these studies provide convincing evidence that higher intensity interval training exacerbates acute molecular interference with muscle hypertrophy induced by RT.

As mentioned above, the best characterized local interference mechanism of CT is an antagonistic interaction between the AMPK and mTORC1 signaling (2). However, Apro et al. showed that the signaling of muscle growth through the mTORC1-S6K1 axis after high-intensity and high-volume resistance exercise is not inhibited by subsequent endurance exercise (1). It is possible that a regimen of previous RT alters hypertrophic response after an overall CT session.

The systemic factors responsible for concurrent interference with muscle hypertrophy and strength are not clearly known. We hypothesized that concurrent interference due to systemic factors would also be associated with interfering AMPK activity for mTOR signaling in upper-body muscle during and/or after high sprint lower-body exercise. We suggest 2 of possible mechanisms, one involves the creatine (Cr) concentration and the other involves reactive oxygen species (RONS). High-intensity RT decreases the concentration of phosphocreatine (PCr) in trained muscle, and this is restored after training (10). Ponticos et al. (17) suggested that AMPK activity is activated by permanently high levels of Cr in the muscle. Slow recovery of increased Cr after RT might activate AMPK. High blood flow in arm muscles is required for early recovery of PCr after exercise, but it should be decreased during high sprint leg exercise because of blood redistribution (13). Therefore, we believed that recovery of PCr concentration after RT in upper-body muscle might not be sufficient after high-intensity lower-body endurance exercise. The slow recovery of Cr might activate AMPK. Another possible factor for systemic concurrent interference is the effect of RONS (15). The RONS are produced during exercise, such as the Wingate test, and play a role in regulating calcium calmodulin kinase (CaMK)-AMPK axis signaling pathway (15). We suspect that RONS produced by sprint leg exercise diffuse systemically and interfere with mTOR activation in arm muscles. Because the findings shown in this study suggest that concurrent interference occur systemically, we will investigate mechanisms such as Cr metabolisms, RONS productions, etc. We believe that the key is to interfere with mTOR signaling during concurrent upper-body ST and lower-body high-intensity interval exercise.

In this study, there are several limitations. The first is our small sample size. Therefore, the chance of committing a type II error in evaluating our measurements was high. Second, we could not control for nutrition factors such as diet and intake of supplements, which could influence the results of our study. We could not evaluate muscle volume, as we only measured a single site of arm CSA. In addition, our exercise protocol (arm-curl exercise) was minimalistic. It would be assumed that greater interference would be found when higher volume protocols are used, particularly involving large, multijoint movements.

In conclusion, our data of a pilot study may indicate that concurrent strength and SIT interfere with muscle hypertrophy and strength, if performed on the same day.

Practical Applications

In this study, the CT group performed SIT immediately after RT. A recent review reported that concurrent strength and endurance training on the same day have higher effect on hypertrophy and strength responses than the two trainings on separate days, although this difference was not statistically significant (21). Cantrell et al. (5) examined the chronic effect of concurrent strength and SIT on strength and hypertrophy on separate days. They suggested that SIT performed concurrently with heavy ST on separate days does not seem to interfere with the development of maximal strength. In addition, aerobic performance seems to respond positively to low-volume, high-intensity SIT. These studies indicate the influence of duration of session interval between RT and endurance training, and the order of exercise performance, on the effects of CT. One explanation could be that endurance training after hypertrophic molecular response does not interfere with anabolic adaptation for RT, considering that numerous animal and human studies have shown activation of mTORC1 signaling in response to ST more than 24 hours after resistance exercise.

Acknowledgments

This work was supported by a Grant-in-Aid for Young Scientists (B15K16467 to N.K.) from the Ministry of Education, Culture, Sports, Science, and Technology.

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