Journal of Strength and Conditioning Research, 2003, 17(3), 503–508

Concurrent Strength and Endurance Training: The Influence of Dependent Variable Selection

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ABSTRACT

Twenty-six active university students were randomly allocated to resistance (R, $n = 9$), endurance (E, $n = 8$), and concurrent resistance and endurance (C, $n = 9$) training conditions. Training was completed 3 times per week in all conditions, with endurance training preceding resistance training in the C group. Resistance training involved 4 sets of upper- and lower-body exercises with loads of 4–8 repetition maximum (RM). Each endurance training session consisted of five 5-minute bouts of incremental cycle exercise at between 40 and 100% of peak oxygen uptake ($\dot{V}O_2$peak). Parameters measured prior to and following training included strength (1RM and isometric and isokinetic [1.04, 3.12, 5.20, and 8.67 rad·s^{-1}] strength), $\dot{V}O_2$peak and Wingate test performance (peak power output [PPO], average power, and relative power decline). Significant improvements in 1RM strength were observed in the R and C groups following training. $\dot{V}O_2$peak significantly increased in E and C but was significantly reduced in R after training. Effect size (ES) transformations on the other dependent variables suggested that performance changes in the C group were not always similar to changes in the R or E groups. These ES data suggest that statistical power and dependent variable selection are significant issues in enhancing our insights into concurrent training. It may be necessary to assess a range of performance parameters to monitor the relative effectiveness of a particular concurrent training regimen.

Key Words: resistance, endurance, training, $\dot{V}O_2$peak

Reference Data: Leveritt, M., P.J. Abernethy, B. Barry, and P.A. Logan. Concurrent strength and endurance training: The influence of dependent variable selection. *J. Strength Cond. Res. 17(3):503–508. 2003.*

Introduction

Many recreational exercisers and athletes endeavor to enhance strength and endurance simultaneously to improve their performance in domestic and athletic contexts. The rationale for this concurrent training is that the benefits from both endurance and resistance training can be simultaneously acquired. Research over the last 2 decades has shown on some, but not all, occasions that strength or endurance development is actually attenuated by concurrent training (5, 11, 13–16, 18, 23). The studies reporting an inhibition in adaptation suggest that simultaneous acquisition of components of fitness during concurrent training may not be possible.

There have been three commonly advanced arguments in relation to why concurrent training may produce an inhibition in the development of strength or endurance. First, the initial bout of activity causes acute fatigue that compromises the overload achieved in the second bout, and over time the adaptation to the second bout of training is less than if there had been no preceding activity (9). There is some evidence for acute fatigue as a phenomenon, but few data to indicate whether over time the small reductions in overload are sufficient to compromise adaptation (2, 19). There are data to suggest that performing resistance and endurance training on the same day may compromise adaptation when compared with alternate-day concurrent training (19). Second, concurrent training causes neuromuscular adaptations that are distinct from endurance or resistance training (8, 12, 19). Again there is some evidence for this contention (15, 18), although much work is still required to describe these differences. Third, an inhibition in strength or endurance adaptation may be due to overtraining, even though this explanation has typically been rejected (11, 12, 16). The role, if any, that these mechanisms have either in isolation or together in inhibiting adaptation during concurrent training will be clarified over time with more research.

These proposed mechanisms however, do not explain why inhibition of adaptation is only seen in some concurrent training studies. Almost certainly differences in the design of concurrent training interventions, nutritional, and training histories of partici-

Table 1. Mean (*SD*) age, height, and weight for subjects in the resistance (R), endurance (E), and concurrent (C) conditions.

	R		E		C	
	Men	Women	Men	Women	Men	Women
Age	19.2 (1.3)	18.3 (0.6)	19.3 (1.5)	19.2 (1.5)	19.3 (1.5)	18.3 (0.8)
Mass	71.7 (9.4)	55.8 (1.8)	75.9 (13.9)	62.0 (6.7)	84.4 (10.7)	64.5 (15.3)
Height	178.6 (3.4)	162.3 (1.5)	179.3 (3.5)	167.5 (4.9)	183.3 (3.1)	165.3 (3.2)

pants, and genetic predispositions of the subjects are implicated in this variation between studies (4, 6, 7, 10, 11). Equally, however, other issues may also be involved, for example, inadequate statistical power may explain the absence of differences between conditions within studies (e.g., changes in 1 repetition maximum [1RM]) (20). In addition, the dependent variables selected in some studies may have been insensitive to the effects of concurrent training; hence, little change in adaptation has been reported in some studies. Abernethy and Jürimäe (3) recently demonstrated that some strength indices are more sensitive than others to the effects of resistance training. Conceivably, some strength and endurance indices may be more sensitive to the positive and/or negative effects of different forms of concurrent training. For example, isoinertial, isokinetic, and isometric strength measures monitoring training adaptations on the same muscle group are often poorly correlated, presumably because they are measuring different structural, neural, and/or muscular phenomena (3, 5). The purpose of this investigation was to determine whether concurrent training produced similar 1RM, isometric, and isokinetic strength, $\dot{V}O_2$peak, and Wingate test adaptations as resistance and endurance training completed in isolation. Critically we used both parametric and effect size (ES) techniques, which quantify the magnitude or meaningfulness of the effect of independent variable manipulations, to ascertain differences in dependent variable scores across training conditions.

Methods

Experimental Approach to the Problem

The purpose of this study was to determine whether concurrent training produced similar changes in endurance and a range of strength and power variables as resistance or endurance training performed in isolation. We selected a range of strength measures because it has previously been shown that some strength indices are more sensitive than others to the effects of resistance training (3). In doing so, it would also be possible to see whether different strength indices were more sensitive to the positive and/or negative effects of concurrent training. The resistance training in this study was designed to enhance strength, and the intensity and duration of the endurance training was similar to that used in other concurrent training investigations (2, 4, 11).

Subjects

Twenty-six active, university students (11 men, 15 women) were randomly allocated to resistance training (R) (n = 8; 5 men and 3 women), endurance training (E) (n =9; 3 men and 6 women), and concurrent training (C) (n = 8; 3 men and 6 women) groups. The groups were of a statistically similar age, weight, and height (Table 1). The participants were active students who participated regularly in social and intramural sports but were neither systematically training for a sport nor undertaking resistance training. The experimental procedures complied with the requirements of the National Health and Medical Research Council and were approved by the Medical Research Ethics Committee of the University of Queensland. Training and testing associated with the experiments were conducted within the facilities of the Department of Human Movement Studies at the University of Queensland.

Design

Subjects completed 6 weeks of R, E, or C training. Dependent variables (isoinertial, isometric, and isokinetic strength, $\dot{V}O_2$peak and Wingate test performance) were measured prior to and following the training period. These measurements were performed on 3 separate days (testing day [TD] 1, 2, and 3), with the order of TDs being fixed but not necessarily the order of tests within each TD. Where testing order was randomized for a particular TD, the order was retained for a given subject at subsequent measurement occasions. Strength tests were performed on TD 1, $\dot{V}O_2$peak measured on TD 2, and Wingate test performance assessed on TD 3.

Dependent Variables

Leg strength was measured isoinertially, isometrically, and isokinetically. Isoinertial strength was assessed by measuring 1RM squat on a Plyopower system (PPS Norsearch, Lismore, Australia). One RM squat was measured after a warm-up consisting of 8 repetitions with a light load. Subjects then performed a single repetition with a heavier load. The weight was then progressively increased until the subject could not successfully complete 1 repetition. A lift was deemed to be successful when subjects could lower the bar such that a knee angle of 90° was achieved and then raise the bar back to the upright starting position. Subjects received approximately 4 minutes of rest between each attempt. One RM was usually determined within 4–6 efforts.

Isokinetic leg strength was determined by measuring leg extension torque at a knee angle 0.52 rad from full extension at contractile velocities of 1.04, 3.12, 5.20, and 8.67 $rad \cdot s^{-1}$ on a Cybex 6000 (Cybex division of Lumex, New York, NY). Isometric strength was determined by measuring peak torque produced during a 5-second isometric knee extension at a knee angle 0.78 rad from full extension.

Wingate test performance was assessed during a 30-second maximal sprint performed on a multigeared air-braked cycle ergometer (South Australian Sports Institute, Brooklyn Park, South Australia) fitted with toe clips and straps. Software developed and marketed by SASI (Cycletest version 3.1b) enabled peak power output (PPO), average power, and relative power decline to be recorded during each test (power sampling occurred at 10 Hz). All tests were conducted using a gear ratio eliciting 8.87 flywheel revolutions per pedal crank revolution.

Pre- and postintervention $\dot{V}O_2$peak was determined using an established protocol (17). Briefly, each subject began cycling at a workload of 50 W on an electrically braked cycle ergometer (Excalibur, Lode, Netherlands). The workload was then increased by 25 W each minute until volitional fatigue. Gas volumes were measured by a turbine ventilometer (Morgan, Kent, England). Concentrations of expired oxygen and carbon dioxide were measured by a gas analysis system (Ametek, Pittsburgh, PA; SOV S3A/1 and COV CD3A). $\dot{V}O_2$peak was determined to be the highest oxygen uptake recorded during the test.

Training Regimens

Training in the R, E, and C conditions was conducted 3 times a week (Monday, Wednesday, Friday) for 6 weeks. The resistance and endurance elements of the C group's training were the same as training undertaken by the R and E groups, respectively. In the C condition, the endurance element of training immediately preceded free weight activity on all training occasions. Endurance training involved five 5-minute bouts of cycle ergometry, each of which were separated by 5 minutes of passive recovery. Work rates for each minute within each cycle bout corresponded with 40, 60, 80, 100, and 100% of the pretraining $\dot{V}O_2$peak, respectively. Exercises incorporated within the free weight training program designed to enhance strength, included the half squat, leg extension, hamstring curl, bench press, lat pull-down, biceps curl, lateral raises, and abdominal crunches. Following a warm-up set, participants completed 3 sets to failure at 8, 6, and 4 RM for half-squats and 10, 8, and 6 RM for all other exercises. Training resistances were adjusted as needed to take into account changes in training repetition maxima. All sets for a given exercise were completed sequentially, and interset and interexercise recoveries were between 3 and 4 minutes in duration. All resistance and endurance training sessions were supervised. No other training was completed during the intervention.

Table 2. Mean (*SD*) pretraining dependent variable scores for the resistance (R), endurance (E), and concurrent (C) conditions.

Parameter	R	E	C
1RM squat (kg)	115 (39)	117 (44)	103 (30)
Isometric 45° (N·m)	189 (68)	197 (63)	185 (61)
1.04 $rad \cdot s^{-1}$ (N·m)	121 (50)	123 (29)	125 (39)
3.12 $rad \cdot s^{-1}$ (N·m)	108 (42)	99 (23)	101 (41)
5.20 $rad \cdot s^{-1}$ (N·m)	74 (32)	65 (23)	74 (32)
8.67 $rad \cdot s^{-1}$ (N·m)	69 (38)	40 (26)	49 (28)
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)*	54 (14)	40 (6)	41 (7)
Peak power output (W)	928 (272)	804 (257)	750 (289)
Average power (W)	612 (177)	574 (172)	531 (186)
% Decrement	51 (13)	50 (6)	48 (18)

* $p < 0.05$ but >0.0167 for differences between the R group and other conditions.

Statistical Analyses

The pre- and posttraining dependent variable scores, and the changes in the scores as a consequence of training were described (means and *SD*s). The data were examined for the presence of outliers and when detected were excluded from subsequent analysis (i.e., 1 posttraining PPO value from the R group; and 1 posttraining $\dot{V}O_2$peak value from both the E and C groups) (21). One-way analyses of variance were used to determine whether differences in pretraining and changes in (post-pre) dependent variable scores between conditions were statistically significant ($p \leq 0.05$). Where they were unmatched *t*-tests were used in post hoc analysis. The alpha level was adjusted to reduce the risk of experiment-wise error in these analyses using the Bonferroni correction. ESs were calculated using pooled *SD*s to quantify the effect that the manipulation of the independent variable had on dependent variable scores (22). ESs of 0.2, 0.5, and 0.8 were accepted as being small, moderate, and large respectively (22).

Results

Prior to training, the differences among the E, R, and C conditions for 1RM, isometric, and isokinetic (with the exception of 8.67 $rad \cdot s^{-1}$) strength were neither significant ($p = 0.86$–0.98) nor noteworthy (ESs = 0.0–0.4) (Table 2). Although the differences at 8.67 $rad \cdot s^{-1}$

Table 3. Mean (*SD*) changes in dependent variable scores as a consequence of 6 weeks training by the resistance (R), endurance (E), and concurrent (C) groups.

Parameter	R	E	C
1RM squat (kg)	33 (17)*	2 (18)	26 (18)*
Isometric 45° (N·m)	6 (18)	16 (24)	9 (35)
1.04 rad·s^{-1} (N·m)	16 (17)	3 (21)	19 (14)
3.12 rad·s^{-1} (N·m)	7 (15)	5 (21)	14 (17)
5.20 rad·s^{-1} (N·m)	11 (14)	17 (30)	8 (12)
8.67 rad·s^{-1} (N·m)	6.25 (5)	20 (29)	15 (15)
$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})†	−8 (12)*	2 (6.7)	2 (5.5)†
Peak power output (W)	62 (70)	13 (62)	24 (81)
Average power (W)	32 (42)	−6 (25)	20 (58)
% Decrement	5 (13)	1 (5)	≈0 (16)

* Significantly different from the E condition ($p < 0.016$).
† Significantly different from R condition ($p < 0.016$).

Table 4. Effect size (ES) changes in dependent variables as a consequence of resistance (R), endurance (E), and concurrent (C) training.

	1RM	Isom	1.04	3.12	5.20	8.67	$\dot{V}O_2$peak	PPO	AvP	% Dec
R	1.5	0.2	0.9	0.4	0.5	0.3	−0.9	0.9	0.7	0.4
E	0.1	0.6	0.2	0.3	0.9	1.0	0.2	0.2	−0.1	0.1
C	1.2	0.3	1.0	0.8	0.4	0.8	0.2	0.3	0.4	≈0.0

were not significant, the ESs suggested that the R group was stronger than the C (ES difference = 0.6) and E (ES difference = 0.9) conditions. The R group had a greater $\dot{V}O_2$peak than the C and E groups (ES differences ≈ 1.2). ES differences suggested that the preintervention PPOs during the Wingate challenge were greater in the R group than the E (0.5) and C (0.6) conditions, although the differences were not significant ($p > 0.05$). Similarly, the R group presented a moderate ES difference to the C group (0.5) in terms of average power. Differences between the groups in terms of power decrement were neither significant nor noteworthy.

Six weeks of training produced a variety of strength, aerobic, and anaerobic adaptations for the R, E, and C groups (Tables 3 and 4). When compared with the E group (ES ≈ 0.0) changes in 1RM squat strength were large and significant for the R and C groups. There was also a significant and large difference in $\dot{V}O_2$peak adaptation between the R group (decrement) and E and C conditions. None of the changes in any of the other dependent variables were statistically significant, although ES transformations suggested that this was, for some measures, because of inadequate statistical power (Table 4). Specifically, the R group produced a moderate increment in average power; the E condition produced large increments in isokinetic strength at 5.20 and 8.67 rad·s^{-1}, and the C group produced moderate increments in isokinetic strength at 1.04 and 8.67 rad·s^{-1}.

Discussion

There was no parametric evidence of an attenuation or potentiation of strength, anaerobic, or $\dot{V}O_2$peak development as a consequence of concurrent training (Table 3). However, the ES data indicated that the interaction was more complex than the parametric data would suggest (Table 4). This complexity was evident at 2 levels. First, the mismatch between ES and parametric analyses suggest that interpretation of some previous concurrent training investigations may have been a little too simplistic. The second mismatch in response between so-called like dependent variables (in this study the strength variables) within a condition reinforces the complex neuromuscular interactions underpinning, in this case, strength adaptation. These data add weight to Kraemer's (15) plea for more research to accurately describe and explain the subtle variations in strength and endurance adaptation accompanying concurrent training when compared with strength or endurance training in isolation.

Moderate to large ES changes in dependent variables were not always accompanied by significant changes as indicated by parametric analyses. This suggested that some important differences among the R, E, and C conditions might not have been detected parametrically because of insufficient statistical power resulting from a relatively small number of subjects in each training group (see within columns of Table 4). This does not mean, however, the differences were not real or confined to this investigation (e.g., 20). Rather, it suggests that our interpretation of concurrent training data may not have been as insightful as it could have been. Alternatively, the duration of the study might not have been long enough for all training effects to be realized. Although this argument has merit, significant differences in concurrent training adaptation have been reported after a similar duration of training (11).

Differences in certain dependent variable scores were evident in the R, E, and C groups prior to training. These differences may have influenced the magnitude of change in dependent variables in response to the training interventions. For example, the small increment in isokinetic strength seen in R group at 8.67 rad·s^{-1} may have been due to the fact that this group was stronger prior to training and therefore had less potential for adaptation (Tables 1 and 4). However, this explanation does not explain why the better R group at the commencement of training in terms of PPO also showed the greatest change with training (Tables 1 and 4).

The variation in strength adaptation seen in Table 4 reinforces the existence of complex, neuromuscular interplays underpinning 1RM, isometric, and isokinetic strength development. Previously we have shown that there is greatest transfer from isoinertial training to isoinertial strength indices (i.e., isoinertial strength greater than isometric and isokinetic strength indices) (3). These data are consistent with this assertion, as is evidenced by the within-row variation seen in Table 4 for the various strength indices. The better sensitivity of isoinertial indices to isoinertial training may be attributed to their congruence (i.e., in terms of structural similarity and/or neural or muscular adaptation) (3, 4). Conversely, the poorer sensitivity of the isometric and isokinetic indices to weight training may be attributed to structural dissimilarity and/or less important neural or muscular adaptations. Unfortunately, our data do not allow us to identify the points of congruence between endurance training and isokinetic strength adaptation at 5.20 and 8.67 rad·s^{-1}.

Many people rationalize that concurrent training will afford them the benefits of both strength and endurance training. The fact that an inhibition in strength or endurance adaptation as a consequence of concurrent training has been reported appears to place in doubt this hypothesis, at least in the contexts of those studies (11, 13, 14). Our data also place in question the notion of a simultaneous acquisition of both strength and endurance with concurrent training. Specifically, only 3 of the 6 dependent variables (1RM, $\dot{V}O_2$peak, and isokinetic strength at 8.67 rad·s^{-1}), which were moderately or largely affected by any form of training, produced similar changes in the C group as the R or E conditions (Table 4). If the simultaneous acquisition of both strength and endurance were possible, then we would have also expected to see changes in average power during the Wingate test and isokinetic strength at 5.20 rad·s^{-1} in the C group as well as R or E groups (Table 4).

Our data suggest that dependent variable selection can influence conclusions made with respect to changes in strength and endurance as a result of concurrent training. However, differences in the design of concurrent training interventions, such as mode, duration, and intensity of training, may influence whether any interference in strength or endurance development is observed. Clearly, the interaction between strength and endurance training is a complex issue, and it may still be possible to design specific concurrent training regimens that can minimize or possibly avoid any interference effects.

Scientists and practitioners alike need to measure changes in strength as a consequence of interventions. This study places in stark relief the question of what dependent variables to measure. We have previously addressed this issue (1). Briefly, we must determine, rather than presume, that there is a relationship between changes in particular dependent variable and changes in a particular movement context (e.g., sports skill or activity of daily living). We cannot discount the possibility that the dependent variables that have been shown to have their adaptation attenuated by concurrent training may have little relationship with ''more realistic'' movement contexts. Equally, the converse may be true. Although this study did not directly relate dependent variable performance to a particular movement context, the variation in strength ESs seen in Table 4 highlights how important dependent variable selection is in the external validity of concurrent training studies. This is not to say that concurrent training research with high internal validity is not important or required but rather that the generalizability of laboratory data to field contexts should not be presumed.

This study has demonstrated that statistical power and dependent variable selection can impact on the interpretation of concurrent training data. Critical to the further investigation of concurrent training is the refinement of strength assessment procedures to ensure that what we are measuring is meaningful to various movement contexts. Hence, our selection of dependent variables should be based not only on those measures with which modulation has been demonstrated but also must consider the relevance of dependent variables to the activity for which concurrent training is being undertaken.

Practical Applications

On occasion parametric analyses may suggest that there is no interaction between strength and endurance activity in the concurrent training context; however, this may simply be due to insufficient statistical power and/or inappropriate dependent variable selection. ES transformations allow us to gauge whether the absence of statistically significant differences is due to insufficient statistical power. The issue of dependent variable selection is more difficult to deal with. One strategy is to measure various aspects of performance in a number of ways (e.g., in this study multiple strength measures were taken). In an applied sporting or recreational context, it is essential that changes in one or more dependent variables meaningfully correlate with changes in the movement context of interest.

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Acknowledgments

This project was funded by the Australian Sports Commission.

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