Exploring the dose-response relationship between resistance exercise intensity and cognitive function

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Abstract:

The purpose of this study was to explore the dose-response relationship between resistance exercise intensity and cognitive performance. Sixty-eight participants were randomly assigned into control, 40%, 70%, or 100% of 10-repetition maximal resistance exercise groups. Participants were tested on Day 1 (baseline) and on Day 2 (measures were taken relative to performance of the treatment). Heart rate, ratings of perceived exertion, self-reported arousal, and affect were assessed on both days. Cognitive performance was assessed on Day 1 and before and following treatment on Day 2. Results from regression analyses indicated that there is a significant linear effect of exercise intensity on information processing speed, and a significant quadratic trend for exercise intensity on executive function. Thus, there is a dose-response relationship between the intensity of resistance exercise and cognitive performance such that high-intensity exercise benefits speed of processing, but moderate intensity exercise is most beneficial for executive function.

Keywords: physical activity | cognition | executive function

Article:

Cognitive ability is important for daily living and is a main component of health-related quality of life (Lox, Ginis, & Petruzzello, 2006). Recently, the relationship between acute exercise and cognition has received particular attention. Although the empirical findings have been mixed, narrative (Brisswalter, Collardeau, & Arcelin, 2002; McMorris & Graydon, 2000; Tomporowski, 2003) and meta-analytic reviews (Etnier et al., 1997) suggest a positive effect of acute exercise on cognitive performance. In attempting to establish the nature of this effect, several studies have been designed to further our understanding of the potential dose-response relationship between exercise intensity and cognitive performance. Results of these studies have also been mixed, and some have concluded that there is an inverted-U relationship (Aks, 1998; Arent & Landers, 2003; Brisswalter, Durand, Delignieres, & Legros, 1995; Chmura, Nazar, & Kaciuba-Uscilko, 1994; Levitt & Gutin, 1971; McMorris & Graydon, 2000; Reilly & Smith, 1986; Salmela &

Ndoye, 1986; Tenenbaum, Yuval, Elbaz, Gar-Eli, & Weinberg, 1993). Others have concluded that the relationship is linear (Allard, Brawley, Deakin, & Elliott, 1989; Davranche & Audiffren, 2004; McMorris & Graydon, 2000), and still others have not found support for a dose-response relationship (Cote, Salmela, & Papathanasopoulu, 1992).

One explanation for these mixed results may relate to the issue of task specificity. Arent and Landers (2003) suggested that a linear relationship might be appropriate for explaining the exercise intensity‑performance relationship for the components of a task that require more motor or peripheral processes, whereas an inverted-U relationship might be appropriate for the components of the task that require greater cognitive or central processes. Similarly, Humphreys and Revelle (1984) suggested that the nature of the dose-response relationship between arousal and cognitive performance is specific to the cognitive task to be performed. In particular, they expect a linear relationship between arousal and performance on sustained information transfer tasks and an inverted-U relationship between arousal and performance on short-term memory tasks. Thus, it may be that the dose-response relationship between exercise intensity and cognitive performance is dependent upon the particular demands of the cognitive task. To date, most acute exercise studies have examined the intensity‑performance dose-response relationships using reaction time tasks (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Cote et al., 1992; McMorris & Graydon, 2000; Salmela & Ndoye, 1986; Tomporowski, 2003). Although a few studies have examined the effect of acute exercise on higher order cognitive tasks (Dietrich & Sparling, 2004; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Lichtman & Poser, 1983; Sibley, Etnier, & Le Masurier, 2006; Tomporowski et al., 2005), none of these studies examined dose-response issues. Therefore, the potential task specificity of the dose-response relationship has not been fully explored.

An additional limitation of the past research is that most of the previous studies have used aerobic exercise modalities, such as jogging or cycling (Brisswalter et al., 2002; McMorris & Graydon, 2000; Tomporowski, 2003), for the acute exercise bout. Resistance exercise is an important mode of exercise that has been demonstrated to improve health-related physical fitness (Buckworth & Dishman, 2002) and to protect against health-related diseases such as osteoporosis, low back pain, hypertension, diabetes, and dyslipidemia (Kraemer, Ratamess, & French, 2002; Winett & Carpinelli, 2001). Further, resistance exercise has been found to affect many of the same mechanisms that have been suggested to explain the effects of an acute bout of aerobic exercise on cognitive performance. In particular, resistance exercise results in increased arousal (Bloomer, 2005) and alterations in plasma catecholamine levels (French et al., 2007; Pullinen, Nicol, MacDonald, & Komi, 1999). However, resistance exercise has largely been ignored in studies testing the effects of acute exercise on cognitive performance, and we are aware of only one published study in which this effect has been reported. Chang and Etnier (2009) examined the effect of a single bout of resistance exercise on cognitive performance as assessed using the Stroop Test and the Trail Making Test. Results were interpreted as indicative of positive effects on both automatic cognitive processes and on particular types of executive function in middle age. However, the researchers did not test dose-response relationships relative to exercise intensity. Understanding dose-response relationships for resistance exercise is important for prescription and for advancing our understanding of potential mechanisms of the relationship. Thus, the purpose of this study is to explore the dose-response relationship between acute resistance exercise intensity and two measures of cognitive performance. We hypothesized that either a linear or an inverted-U dose-response relationship would explain the relationship between exercise intensity and performance and expected that the nature of the relationship would differ as a function of the specific cognitive task being performed.

Method

Participants

Sixty-eight men and women (*M* = 25.95 years, *SD* = 3.20) were recruited. Inclusion criteria were assessed using the Physical Activity Readiness Questionnaire (PARQ) to ensure that it was safe for the participant to perform this series of resistance exercises. This approach follows the guidelines of the American College of Sports Medicine (American College of Sports Medicine, 2007). Sample size was based on a power analysis using a 2 × 4 mixed design. The protocol was approved by the university committee for institutional review.

Resistance Exercise Intervention

The resistance exercise protocol was selected based on the protocol used by Arent et al. (2005) who examined dose-response relationships between resistance exercise and affect using intensities of 40%, 70%, and 100% of 10-RM. Using heart rate, ratings of perceived exertion (RPE), and salivary cortisol, these intensities were confirmed to represent low, moderate, and high exercise intensities, respectively. The abbreviation *10-RM* means the participant can lift the load 10 repetitions before exhaustion. The use of 10 repetitions for the conditions is consistent with the 8–12 repetitions per set suggested by ACSM for increasing muscular strength, endurance, and hypertrophy. The resistance exercise session of the present protocol included two sets of 10 repetitions for each of six muscle groups: bench presses, right and left rowing, lateral arm raise, and right and left arm curl. The rest period between sets and between exercises was 2–4 min.

Measures

Potential Confounds

Demographic Variables. Age was assessed by self-report. Height and weight were measured in the laboratory. Body mass index (BMI) was computed by dividing weight by the square of height (kg/m2). Participation in physical activity was assessed using the Aerobics Center Longitudinal Study Physical Activity Questionnaire (ACLSPAQ; Kohl, Blair, Paffenbarger Jr., Macera, & Kronenfeld, 1988). The ACLSPAQ has established validity with correlations ranging from *r* = .35 to 0.51 with treadmill time and reported frequency of sweating (Kohl et al.). Responses on this questionnaire were converted to MET-hours per week using the published guidelines (Ainsworth, et al., 1993).

The Feeling Scale. The Feeling Scale (FS) is a subjective self-report single-item scale used to assess the valence of affect (Hardy & Rejeski, 1989; Svebak & Murgatroyd, 1985). The FS ranges from −5 (*very bad*) to +5 (*very good*) with 0 (*neutral*) as the midpoint. This self-report measure was used to identify the potential confounding influence of anxiety on the dose-response relationship between resistance exercise intensity and cognitive performance. The FS measure used in the statistical analyses was the average of the FS scores assessed during the treatment session for each individual ($FS_{average}$).

Exercise Intensity Manipulation Check

Heart rate (HR), Ratings of Perceived Exertion (RPE), and Felt Arousal Scale (FAS) were assessed to confirm the exercise intensity manipulation.

Heart Rate. Heart rate was monitored by short-range radio telemetry devices (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland) during the entire treatment and cognitive task performance sessions. The HR monitor consists of an elastic band that is strapped around the chest to hold a rubber pad (that contains the HR measuring device with the transmitter) in place just below the sternum, and a wristband receiver. The participant's HR is displayed on the face of the wristband receiver. Data from the HR monitor were recorded at 1-min intervals. Two HR variables, HR_{peak} and $HR_{average}$, were identified. The variable HR_{peak} represents the highest HR attained during the treatment session for each individual, and $HR_{average}$ represents the average HR during the treatment session for each individual.

Ratings of Perceived Exertion. The RPE scale, developed by Borg (1982), provides a subjective rating of each individual's perception of effort during exercise. The original Borg scale ranges from 6 to 20. From 6 to 11 is recognized as "very, very light to fairly light"; from 12 to 13 is recognized as "somewhat hard"; and from 16 to 20 is recognized as "hard to very hard" (Pollock, Wilmore, & Fox, 1984). The term $RPE_{average}$ represents the average of the RPE scores during the treatment session for each individual.

Felt Arousal Scale. The FAS is a subjective self-report single-item scale used to assess the intensity of arousal (Hardy & Rejeski, 1989; Svebak & Murgatroyd, 1985). The FAS is a 6-point scale measuring perceived activation that ranges from 1 (*low arousal*) to 6 (*high arousal*), and was applied to assess the change of self-reported activation relative to the acute resistance exercise. The term $FAS_{average}$ represents the average of the FAS score during the treatment session for each individual.

Cognitive Performance

Stroop Test. The Stoop Test (Stroop, 1935), also referred to as the *Color Naming Task*, is used to assess information processing speed, executive abilities, selective attention, and the ability to inhibit habitual responses (Pachana, Thompson, Marcopulos, & Yoash-Gantz, 2004). In the Stroop Word (SW) condition, participants see color names written in black ink and are asked to read the word aloud. In the Stroop Color (SC) condition, participants see rectangles printed in one of four colors of ink and are instructed to verbally identify the color of the ink. In the Stroop Color-Word (SCW) condition, participants see color names printed in different colors of ink (such as the word *RED* printed in green ink) and are instructed to verbally identify the color of the ink. The stimuli for the Stroop test were provided using a standard paper format. Stimuli were displayed on an 8.5- × 11-inch sheet of paper that was placed in front of the participant, and the stimuli were arranged in three columns of 50 stimuli. Participants were instructed to start with the left-most column and to work down the column before moving to the next column to the right. If a mistake was made, the examiner would say “incorrect” and would point to the stimulus that resulted in the mistake. The participant was instructed to verbally correct his or her mistake and then to continue. The test-retest reliability of the Stroop Test is approximately 0.84 (Siegrist, 1997).

Paced Auditory Serial Addition Task. The Paced Auditory Serial Addition Task (PASAT) has been widely used to measure information processing, attention, and concentration (Deary, Langan, Hepburn, & Frier, 1991). The test requires participants to listen to a series of 60 digits and to verbally provide the sum of each consecutive pair of numbers. Specifically, each participant adds the most recently heard number to the number immediately preceding it and then provides the sum orally. The numbers are provided via an audiotape cassette. The speed at which the numbers are presented increases with each trial, from Trial 1 to Trial 4 (2.4, 2.0, 1.6, and 1.2 s per digit, respectively). Before performing the task, participants were read standard instructions and given examples to allow them to demonstrate their understanding of the task requirements. Feedback was not provided during the actual test. The correct responses for each series (Trial 1 to Trial 4) were analyzed. Cronbach’s alpha for the four PASAT trials has been reported as 0.96 (Egan, 1988).

Procedures

Participants were requested to come to the Sport and Exercise Psychology Laboratory for two separate testing days that were at least 48 hr apart. During Day 1, the participant was presented with a brief introduction to the study by the investigator. The participant also filled out the Institutional Review Board-approved consent form, a demographic questionnaire, the Physical Activity Readiness Questionnaire (PARQ), and the Aerobics Center Longitudinal Study Physical Activity Questionnaire (ACLSPAQ). The PARQ was used to ensure that it was safe for the participant to complete the resistance exercise bout. Participants who answered yes to any of questions were not included in the study. The ACLSPAQ was used to determine the amount of physical activity performed weekly.

After completing the questionnaires on Day 1, the participant was instructed to attach the HR monitor and to sit quietly in a comfortable chair in a dimly lit room for 15 min. Heart rate, FAS, and FS were assessed, and then the participant was asked to complete the Stroop Test and PASAT to provide baseline measures. Lastly, each participant’s 10-RM for each of the six muscle groups was determined. Participants were stratified by sex, and then randomly assigned into a control group or one of three resistance exercise intensity groups (40%, 70%, or 100% of 10-RM). Participants were not told which treatment group they were going to be in for Day 2 until after the pretest on that day. During Day 2, the participant was again asked to sit quietly in a comfortable chair in a dimly lit room for 15 min. Then, pretest scores for the Stroop Test and PASAT were assessed. In the exercise groups, participants performed two sets of 10 repetitions for each of the six exercises at either 40%, 70%, or 100% of 10-RM. The measures HR, RPE, FS, and FAS were assessed at six times (immediately following each of the six exercises), and then HR_{peak} was identified and averages for HR ($HR_{average}$), RPE ($RPE_{average}$), FS ($FS_{average}$), and FAS ($FAS_{average}$) were computed and used for data analysis. Participants in the control group were asked to watch a video on resistance exercise training for an amount of time that was similar to that needed for the treatment groups to perform the resistance exercise (determined through pilot testing), and HR and FAS were then assessed after watching the video. Following completion of the assigned treatment condition, the Stroop Test and PASAT were performed to provide posttest measures. Each day of testing lasted approximately an hour.

Data Analysis

This was a randomized controlled trial with two independent variables: treatment group and time. The variables that were used to confirm the exercise intensity manipulation were HR_{peak}, $HR_{average}$, $FAS_{average}$, and $RPE_{average}$. The variable $FS_{average}$ was used to assess self-reported anxiety in response to the resistance exercise. Cognitive performance on the SW, SC, and SCW (time required to complete each condition) and on Trials 1–4 of the PASAT (number of correct responses) were used as the measures of cognitive performance.

To ensure that the treatment groups were equivalent on potential confounds, one-way ANOVA was computed for age, height, weight, BMI, ACLSPAQ, and baseline measures of HR, FAS, and FS. Separate one-way multivariate analysis of variance (MANOVA) was computed for baseline measures on the Stroop Test (SW, SC, SCW) and the PASAT (Trials 1–4).

To test the exercise intensity manipulation, one-way MANOVA was used to estimate the effect of exercise intensity variables on HR_{peak}, $HR_{average}$, $FAS_{average}$, and $RPE_{average}$. One-way ANOVA was computed for the posttest measure of FS to identify differences in anxiety between the groups. If differences were observed for anxiety, this variable would be included as a covariate in the analyses of the cognitive performance data. When significant effects were identified, Tukey post hoc comparisons were conducted to identify statistically significant differences among the four exercise intensity groups.

To test the dose-response relationship between exercise intensity and cognitive performance, regression analyses with linear and quadratic models were computed using exercise intensity as the predictor and the difference scores between posttest and pretest for the cognitive performance measure as the criterion. Separate regressions were conducted for each cognitive performance measure. Difference scores were used as the criteria for two reasons. First, there was a statistically significant difference in performance on the SCW at the pretest, $F(3, 61) = 3.36$, $p < .05$. Second, because one cannot rely on randomization to ensure that the groups are equal at the pretest, it was necessary to take pretest performance into account in ascertaining the effect of the treatment on cognitive performance. Means and standard deviations at the pretest and posttest as a function of treatment groups, and difference scores between posttest and pretest are presented in Table 3.

An alpha of .05 was used as the level of statistical significance for all statistical analyses, which were conducted using SPSS 15.0.

Results

Three participants failed to complete all of the cognitive assessments and were eliminated from the analyses. Table 1 includes the demographic data and baseline scores of the participants.

Table 1. Means and Standard Deviations for Participant Demographic Information and Baseline Scores

Variable	Exercise Intensity				Total
	Control *M* (*SD*)	40% 10 RM *M* (*SD*)	70% 10 RM *M* (*SD*)	100% 10 RM *M* (*SD*)	*M* (*SD*)
Demographic Information					
Sample size	16	16	16	17	65
Female	8	8	8	8	32
Age (yr)	26.00 (3.41)	25.88 (3.67)	25.69 (3.38)	26.24 (2.59)	25.95 (3.20)
Height (cm)	170.08 (11.19)	171.12 (12.00)	168.33 (8.16)	168.92 (5.92)	169.60 (9.41)
Weight (kg)	72.41 (18.12)	68.43 (19.20)	63.78 (12.00)	70.63 (14.84)	68.84 (16.21)
ACLSPAQ	28.40 (15.96)	34.48 (20.69)	32.13 (24.68)	20.40 (10.59)	28.76 (19.02)
BMI (kg/m^2)	24.78 (4.54)	23.13 (5.34)	22.41 (3.34)	24.64 (0.50)	23.76 (4.50)
Baseline measures of arousal and cognitive performance					
HR	76.13 (7.83)	68.13 (10.01)	69.38 (7.48)	73.06 (11.00)	71.69 (9.55)
FAS	2.72 (0.45)	2.27 (0.72)	2.41 (0.46)	2.67 (0.52)	2.52 (0.56)
FS	2.50 (1.51)	2.56 (1.50)	2.78 (1.49)	2.47 (1.66)	2.58 (1.51)
SW	18.67 (3.75)	19.92 (3.22)	20.30 (3.76)	19.86 (6.15)	19.69 (4.34)
SC	23.87 (5.27)	26.17 (3.84)	25.71 (4.73)	24.97 (5.87)	25.18 (4.96)
SCW	34.18 (6.34)	37.02 (6.01)	40.21 (7.70)	37.73 (8.16)	37.29 (7.28)
Trial 1 of PASAT	43.63 (11.24)	45.25 (8.99)	41.19 (10.08)	42.53 (9.32)	43.14 (9.82)
Trial 2 of PASAT	39.25 (13.01)	39.88 (9.89)	37.94 (9.38)	36.47 (10.29)	38.35 (10.56)
Trial 3 of PASAT	36.44 (11.14)	35.06 (10.40)	31.50 (11.18)	34.18 (6.63)	34.29 (9.90)
Trial 4 of PASAT	25.38 (9.75)	23.56 (9.77)	23.75 (6.18)	23.59 (6.30)	24.06 (8.01)

Note. ACLSPAQ (MET-hours/week) = the aerobics center longitudinal study physical activity questionnaire; BMI = body mass index; HR (bpm) = heart rate; FAS = felt arousal scale; FS = feeling scale; SW = Stroop word (seconds); SC = Stroop color (seconds); SCW = Stroop color word (seconds); PASAT = Paced Auditory Serial Addition Task (number of correct responses).

Potential Confounds

One-way ANOVA revealed that there were no significant differences ($p > .05$) among the four groups in age, $F(3, 61) = 0.08$; height, $F(3, 61) = 0.27$; weight, $F(3, 61) = 0.84$; ACLSPAQ, $F(3, 59) = 1.71$; BMI, $F(3, 61) = 1.08$; baseline HR, $F(3, 61) = 2.49$; baseline FAS, $F(3, 61) = 1.27$; or baseline FS, $F(3, 61) = 0.13$. One-way MANOVA revealed that there were no significant effects of treatment group on baseline Stroop performance, Wilks's $\Lambda = 0.87$, $F(59, 143) = 0.96$, $p > .05$, multivariate $\eta^2 = 0.05$, or on baseline Trial 1 to Trial 4 of PASAT performance, Wilks's $\Lambda = 0.88$, $F(58, 153) = 0.63$, $p > .05$, multivariate $\eta^2 = 0.04$. Means and standard deviations for participant demographic information and baseline scores are presented in Table 1.

Manipulation Check

One-way MANOVA revealed that there were significant effects of the exercise intensity manipulation on HR_{peak}, $HR_{average}$, $FAS_{average}$, and $RPE_{average}$, Wilks's $\Lambda = 0.02$, $F(57, 151) = 44.01$, $p < .05$, multivariate $\eta^2 = 0.74$. Follow-up post hoc analyses revealed that each higher level of exercise intensity resulted in a significantly greater level of arousal as assessed by HR_{peak}, $HR_{average}$, $FAS_{average}$, and $RPE_{average}$. Means and standard deviations for the data reflecting the exercise intensity manipulation check are presented in Table 2.

Table 2. Means and Standard Deviations for the Exercise Intensity Manipulation Check

	Exercise Intensity				
Variable	**Control** *M* (*SD*)	**40% 10 RM** *M* (*SD*)	**70% 10 RM** *M* (*SD*)	**100% 10 RM** *M* (*SD*)	**Total** *M* (*SD*)
HR_{peak}	79.13 (9.32)	100.31 (10.05)	121.50 (14.45)	142.65 (19.06)	111.55 (27.44)
HRavg	79.13 (9.32)	94.88 (9.17)	116.32 (13.73)	135.74 (19.27)	106.96 (25.48)
$RPE_{average}$	N/A	11.14 (1.77)	16.52 (1.16)	19.02 (0.59)	15.65 (3.54)
$FAS_{average}$	2.75 (0.45)	3.38 (0.47)	3.94 (0.40)	4.85 (0.42)	3.75 (0.89)

Note. The values were assessed during each treatment condition (immediately following each of the six resistance exercises performed during the resistance exercise treatment). N/A= value was not assessed.

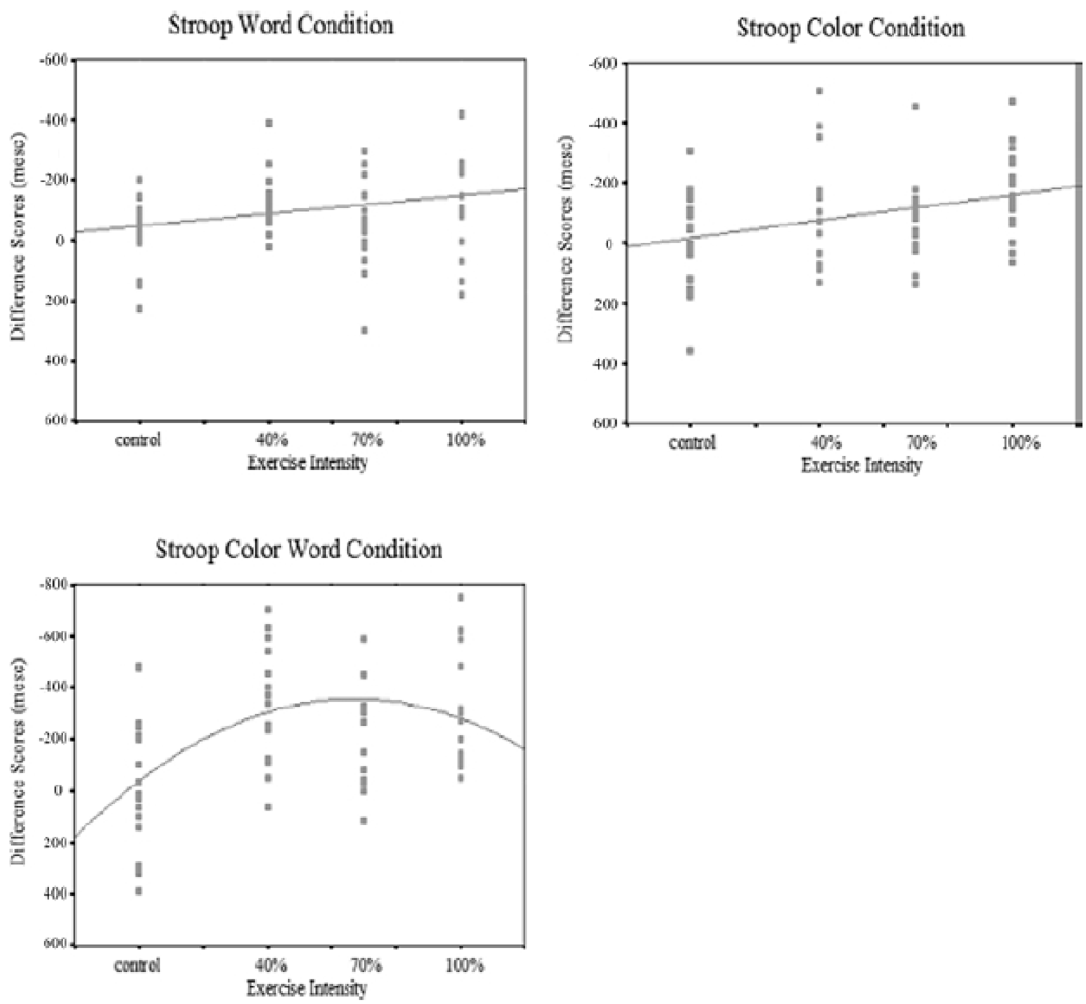

Figure 1. Stroop Test performance as a function of exercise intensity. Values for the Stroop Tests are in milliseconds; thus, a lower score is indicative of better performance and a negative difference score is indicative of improved performance from pretest to posttest. The *x*-axis represents the exercise intensity group (control and 40%, 70%, and 100% 10-RM). The line represents the line of best fit for each distribution.

Dose-Response Relationship

Regression analysis revealed a significant linear trend for the relationship between exercise intensity and SC performance, $F(1, 62) = 3.72$, $p < .05$, $R^2 = 11\%$. Although SW performance revealed a close linear trend between performance and exercise intensity, which accounted for 5.4% of the variance in performance, it did not reach statistical significance, $F(1, 63) = 3.61$, $p = .06$. In contrast, a significant quadratic trend was observed for the relationship between exercise intensity and SCW performance, $F(1, 62) = 7.34$, $p < .001$, $R^2 = 19\%$. These performance curves are illustrated in Figure 1.

In terms of the PASAT, exercise intensity significantly predicted performance in quadratic trends on Trials 2, 3, and 4 performances, Fs $(1, 62) > 7.06$, ps $< .01$. These results accounted for 23%, 35%, and 39% of the variance in performance, respectively. These performance curves are illustrated in Figure 2. Means and standard deviations at the pretest and posttest as a function of treatment group, and difference scores between posttest and pretest are presented in Table 3.

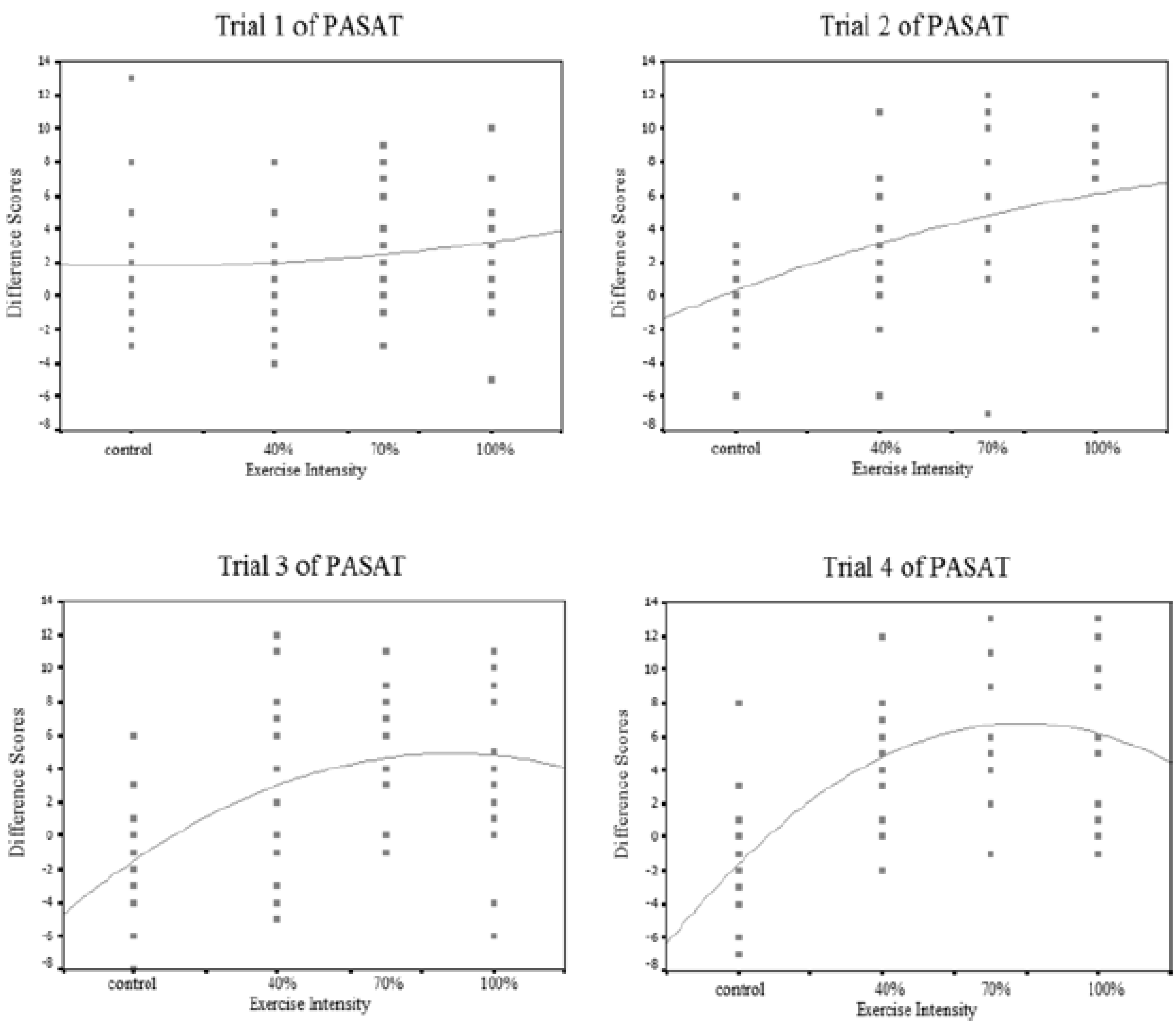

Figure 2. PASAT performance as a function of exercise intensity on Trials 1, 2, 3, and 4 performance conditions. Values for the PASAT are the numbers of correct responses; thus, positive difference scores are indicative of improved performance from pretest to posttest. The *x*-axis represents the exercise intensity group (control and 40%, 70%, and 100% 10-RM). The line represents the line of best fit for each distribution.

Table 3. Means, Standard Deviations, and Difference Scores for the Stroop Test and PASAT Measures Relative to Exercise Intensity

	Exercise Intensity											
	Control			**40% 10 RM**			**70% 10 RM**			**100% 10 RM**		
	Pretest	**Posttest**		**Pretest**	**Posttest**		**Pretest**	**Posttest**		**Pretest**	**Posttest**	
Variable	***M* (*SD*)**	***M* (*SD*)**	**DS**	***M* (*SD*)**	***M* (*SD*)**	**DS**	***M* (*SD*)**	***M* (*SD*)**	**DS**	***M* (*SD*)**	***M* (*SD*)**	**DS**
Stroop Test												
SW	17.70 (3.21)	17.31 (2.91)	–0.39	19.65 (2.49)	18.28 (2.50)	–1.37	19.37 (3.42)	18.79 (3.06)	–0.58	18.80 (3.42)	17.09 (3.10)	–1.71
SC	21.32 (4.63)	21.17 (4.09)	–0.15	23.94 (3.65)	22.87 (2.98)	–1.07	23.93 (4.02)	23.22 (4.25)	–0.71	21.89 (3.23)	20.13 (3.25)	–1.76
SCW	28.53 (5.62)	28.40 (5.55)	–0.13	33.54 (4.45)	29.94 (5.50)	–3.6	33.71 (4.90)	30.84 (4.43)	–2.87	32.18 (5.80)	29.13 (4.88)	–3.05
PASAT												
Trial 1	50.25 (9.23)	51.94 (8.96)	1.69	51.75 (8.09)	53.06 (6.77)	1.31	49.88 (8.90)	53.56 (7.46)	3.68	52.18 (6.10)	55.00 (4.18)	2.82
Trial 2	47.06 (10.51)	47.69 (10.59)	0.63	46.81 (9.92)	48.88 (8.87)	2.07	43.81 (9.47)	49.56 (9.51)	5.75	46.00 (9.21)	49.51 (8.74)	3.51
Trial 3	43.13 (13.48)	41.88 (13.92)	–1.25	42.06 (11.39)	44.38 (10.09)	2.32	37.63 (10.90)	42.56 (9.85)	4.93	39.82 (8.13)	43.35 (10.49)	3.53
Trial 4	32.75 (10.69)	30.50 (10.71)	–2.25	29.06 (10.30)	34.31 (10.00)	5.25	26.19 (7.32)	32.56 (9.03)	6.37	28.41 (8.01)	33.05 (9.60)	4.64

Note. SW= Stroop word (seconds); SC = Stroop color (seconds); SCW = Stroop color word (seconds); DS = difference in mean performance between posttest and pretest; PASAT = Paced Auditory Serial Addition Task (number of correct responses). Values for the Stroop Tests measures are in milliseconds; thus, a negative DS is indicative of an improvement in performance from pretest to posttest. Values for the PASAT are the number of correct responses; thus, a positive DS is indicative of an improvement in performance from pretest to posttest.

Discussion

The purpose of this study was to examine the dose-response relationship between acute resistance exercise intensity and cognitive performance on two types of cognitive tasks. Using the 10-RM as a standard, the intensity of the resistance exercise was manipulated. Exercise-induced arousal as indexed by HR_{peak}, $HR_{average}$, $FAS_{average}$, and $RPE_{average}$ revealed significant differences among the four treatment groups, as anticipated. In addition, the greatest values were seen in the 100% 10-RM group, followed by the 70% 10-RM group, then the 40% 10-RM group, and finally the control group. This finding indicates that an appropriate manipulation of resistance exercise intensity was used. The finding is also consistent with previous research that has used this protocol to create varying resistance exercise intensities (Arent et al., 2005). Importantly, FS did not differ between treatments, suggesting that negative feelings or anxiety did not explain the differences in cognitive performance between the treatment groups.

The Stroop Test is one of the most widely used neuropsychological assessments for the measurement of cognitive function. Performance on the SW and SC conditions is used as a measure of speed of basic information processing, and performance on the SCW condition is used as a measure of executive functions such as inhibition, selective attention, and shifting ability (Miyake et al., 2000; Pachana et al., 2004). Generally speaking, the findings of this study were similar to studies testing the effects of aerobic exercise on Stroop performance (Hogervorst et al., 1996; Lichtman & Poser, 1983; Sibley et al., 2006). That is, the results indicated that resistance exercise has benefits for both simple speed of information processing and the executive functions necessary to perform the SCW. Furthermore, the results extend the research by examining the dose-response effect on the Stroop Test relative to exercise intensity.

The findings indicated that performance on the SC condition, which represents basic speed of information processing, improved linearly with increasing exercise intensity. This supports previous research findings that noted a positive linear relationship between exercise intensity and speed of performance when a participant is familiar with the required skill set or the dominant response for that participant is being tested (Adam, Teeken, Ypelaar, Verstappen, & Paas, 1997; Aks, 1998; Allard et al., 1989; McGlynn, Laughlin, & Bender, 1977; McMorris & Graydon, 2000; Tenenbaum et al., 1993). Interestingly, although performance on the SW condition demonstrated a similar linear trend, it did not reach statistical significance. Given that the two conditions are believed to assess similar underlying cognitive functions, that the p-value ($p = .06$) nearly met the .05 criterion, that the nature of the relationship between exercise intensity and cognitive performance on the SW and SC tasks was essentially the same (i.e., both showed a linear relationship), and that the findings for the SW condition were as hypothesized, we do not believe that the lack of significance for SW represents a meaningful difference in findings. Of course, future research will be needed to confirm the reliability of these results for both measures of information processing.

In contrast to the findings for SC and SW, a quadratic relationship was found for the relationship between exercise intensity and both SCW and PASAT performance. As mentioned, the SCW indexes the executive functions of inhibition, selection attention, and shifting. The cognitive demands of the PASAT include an active maintenance and control of task-relevant information, and cognitive operations involved in working memory (Gonzalez et al., 2006), divided attention

(Kinsella, 1998), and information processing (Shucard et al., 2004). The results of this study indicated that there is a positive effect of acute resistance exercise on executive functions as assessed using both the SCW and the PASAT. Furthermore, the results extend research by demonstrating that the relationship between exercise intensity and executive function performance is quadratic. Interestingly, with increasing difficulty in the PASAT trials, the quadratic relationship tended to become more representative of an inverted-U relationship (see Figure 2) suggesting the role of task difficulty on this relationship. This inverted-U relationship is consistent with previous literature using relatively complex cognitive assessments (i.e., choice reaction time; Chmura et al., 1994; Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo, Nishihira, Hatta, Kaneda, Wasaka et al., 2004; Reilly & Smith, 1986; Salmela & Ndoye, 1986). It is also consistent with recent reports by Kamijo et al. (2004) that moderate exercise induced significantly larger P300 amplitude (an indicator of the amount of attentional resource demands for a specific task) than control, low, and high exercise intensity conditions.

In summary, the findings of this study indicate that a 30-min bout of resistance exercise has a task-specific positive impact on information processing and on executive function. Specifically, these findings indicate that there is a significant linear relationship between exercise intensity and information processing speed. On the other hand, a significant quadratic relationship was observed for exercise intensity and higher-order cognitive measures that assess inhibition, working memory, and attentional flexibility. The results of this study are consistent with conclusions drawn by other researchers suggesting that the relationship between exercise intensity and cognitive performance is moderated by task type (Arent & Landers, 2003; Humphreys & Revelle, 1984). In this study, the tasks were differentiated by the type of cognitive ability being assessed and by task complexity. Future research will be necessary to further our understanding of how these two variables moderate the relationship.

This study had several strengths. First, it is one of only a few empirical studies that has examined the benefit of resistance exercise on cognitive ability. In addition, this is the first study to assess the dose-response effect of resistance exercise intensity on cognitive performance. In addition, the cognitive measures included both basic information processing and executive function, allowing for an examination of the task specificity of the effects. The study also has some limitations. First, although there was no significant difference in weekly physical activity participation, most of the participants did not report participation in resistance exercise during the previous week (on the ACLSPAQ, 78% reported no resistance exercise activity during the previous week). Thus, the results of this study might not generalize to participants who are more experienced with resistance exercise. However, we did not observe any differences on the FS as a function of the treatment condition, suggesting that participants did not experience anxiety in response to the exercise. Secondly, given that the sample in this study consisted of persons from 18 to 31 years of age with college or higher education level, caution is urged in generalizing these findings to other populations.

Based upon these findings, suggestions for further research in this area are warranted. First, given that this is the first published study in which the dose-response effects of acute bouts of resistance exercise on cognition have been tested, further studies should be conducted to ensure that these results are replicable. Once the dose response is further confirmed, the results will be useful for identifying the optimal intensity at which acute exercise benefits cognitive performance. Next, it is recommended that future research examine other physiological variables such as plasma catecholamines in an effort to identify mediators. Studies by Chmura et al. (1994) and McMorris and Graydon (2000) have demonstrated that physiological measures such as blood lactate, plasma adrenaline, and plasma noradrenaline are significantly related to cognitive performance, thus implying their potential roles as mediators of the relationship between exercise intensity and cognitive performance. Lastly, both cognitive performance and physical capacity decline in relatively young age. Future research should assess whether the same dose-response effect exists in other populations, such as middle-aged and older adult populations.

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