The Acute Effect of Exercise on Executive Function and Attention: Resistance Versus Aerobic Exercise

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ABSTRACT

Acute aerobic exercise was shown to enhance such cognitive functions as executive function (EF) and attention. Acute resistance exercise was also shown to enhance cognitive functions, however, only few studies directly compared these two exercise modalities. The aim of this study was to evaluate the acute effect of a typical moderate intensity resistance exercise session as compared to a typical moderate intensity aerobic session, on executive function and attention. A counter-balanced repeated measures experimental design was applied. Forty physical education students (21 women; 19 men, age = 25.7±2.84 years) were tested before and after three sessions: aerobic, resistance, and control. Each session consisted of 30 minutes of exercise or a rest. Executive function and attention were assessed by components of the computerized Stroop Catch game and Go-NoGo cognitive tests. A two-way ANOVA showed a greater increase in attention scores after the resistance sessions ($p < .05$) compared to the control condition. Attention scores in the aerobic sessions showed a trend toward improvement but did not reach statistical significance. Scores of EF significantly increased, both after the resistance session and the aerobic session ($p < .05$), but not after rest in the control condition. Our findings show that an acute session of resistance exercise increased both Attention and EF test scores, while an aerobic exercise session improved only the EF scores.

KEYWORDS

cognitive function
physical activity
cycling
strength

INTRODUCTION

In a recent review, Basso and Suzuki (2017) summarized a large body of research describing the significant changes that occur at the cognitive, behavioral, neurophysiological, and neurochemical levels after a single bout of physical exercise. However, most of the interventions they describe are in the domain of aerobic exercise of various durations and intensities. For example, they provide ample evidence of specific effects of acute aerobic exercise on executive function (EF) and attention. Acute aerobic exercise is a one-session intervention, which may involve 25 min of treadmill or cycle exercise at a target heart rate of 60% of the heart rate reserve (Bullock & Giesbrecht, 2014; Dunsky et al., 2017; Netz et al., 2016; Tine, 2014; Zimmer et al., 2016). Importantly, acute aerobic exercise differs from acute resistance exercise in the immediate acute physiological responses, as well as in the long-term physiological adaptations (Knuttgen, 2007).

Acute moderate-intensity aerobic exercise was found to improve EF, as indicated by higher scores in the interference phase of the Stroop test in endurance athletes (Hogervorst, Riedel, Jeukendrup, & Jolles,

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1996), and in young adults (Tam, 2013). Interestingly, the improvement in the interference phase of executive control in young athletes was explained by improved attention (Chang, Pesce, Chiang, Kuo, & Fong, 2015). Not all studies showed positive effects of aerobic exercise on the interference test. For example, in older participants, a positive effect was reported only in the noninterference phase (Barella, Etnier, & Chang, 2010). Relatively fewer studies examined the effects of acute resistance exercise. It was shown that in adults with impaired cognitive function, resistance exercise improved global cognitive function and EF (Fiatarone Singh et al., 2014). In middle-aged participants, Stroop test scores were improved after an acute moderate resistance exercise (Chang & Etnier, 2009).

In a meta-analysis on the effects of acute exercise on cognitive functions, Chang, Ku, Tomporowski, Chen, and Huang (2012) name a number of variables that may moderate these effects, including: mode of exercise (e.g., aerobic or resistance exercise), duration and intensity of the exercise, time of testing (during or after the exercise bout), participants' age and baseline health, fitness and cognitive functioning, and the complexity and type of the tested task. Thus, it is not surprising that many inconsistencies may be found in the literature (Chang, Labban, Gapin, & Etnier, 2012; Johnson et al., 2016).

Studies designed to directly compare the effects of acute resistance exercise with those of acute aerobic exercise on cognitive function of young, healthy subjects are scarce. Positive effects of acute resistance and aerobic exercise on EF were shown in older women (Alves et al., 2012) and high school students (Harveson et al., 2016). However, a study performed on young people aged 20.2±0.3 years showed improvement in memory only following aerobic exercise, and not resistance exercise (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009).

Recently, Dunsky et al. (2017) examined the influence of acute aerobic versus resistance exercise session on attention and executive function in healthy middle-aged participants. Their main finding was that changes in attention scores following aerobic exercise were significantly higher than those following the control condition.

Johnson et al. (2016) compared the cognitive performance of older adults aged 71-72 years using the Stroop test before and after an acute aerobic or resistance exercise session. They also give a review of the findings concerning the effects of acute aerobic and strength exercise, and discuss the difficulties in comparing their effects on cognitive performance. They also point out the various factors which may influence the results of such investigations (Johnson et al., 2016).

The limited amount of data directly comparing the effects of acute resistance exercise and acute aerobic exercise on cognitive function of young and healthy participants has led to the objective of the current study. Our purpose was to compare the acute effects of a typical moderate-intensity resistance exercise session with the acute effects of a typical moderate-intensity aerobic exercise on cognitive functions relating to EF and attention in a group of young, healthy physical education students familiar with both training modes.

Exercise may prove to be an effective therapeutic tool for delaying or treating cognitive decline, and may also prove to be an effective tool for the enhancement of cognitive functions in healthy individuals. A single bout of acute exercise may also prove to be a practical tool for improving functioning in stressful situations or in an academic environment during learning and test-taking. Resistance or strength training is a popular training mode, and many young and healthy people prefer this training mode and limit their involvement in aerobic training.

METHOD

All participants provided written informed consent for participation in the study, and the study was approved by the Ethics Committee of the Hillel Yaffe Medical Center (Hadera, Israel).

Participants

Participants were volunteers recruited from students enrolled in a degree program in physical education at the Wingate Academic College. Forty physical education students (21 women), aged 25.7±2.84 years, participated in the study. All of the students were familiar with both training modes. Inclusion criteria were: non-smoking, no neurological or psychiatric disease, no prescribed medications that might alter cognitive function, and no head injury or long-term hospitalization in the previous three months.

Procedure

Participants visited the lab four times, each visit no more than one week from the previous visit. They were asked not to engage in any structured exercise on the day of their testing session, and not to consume caffeine for at least two hours prior to the session.

The visits were in the following order:

SESSION 1: BASELINE TESTING

Participants completed an informed consent form and then performed an aerobic fitness trial and resistance exercise trial for assessment. They then performed a familiarization trial of the cognitive tests.

SESSION 2: AEROBIC FITNESS ASSESMENT

A progressive, maximal cycle exercise test (modified from the American College of Sports Medicine, ACSM, in 2010; ACSM, Thompson, Gordon, & Pescatello, 2010) on a Monark 834k cycle ergometer (Monark, Stockholm) was performed. The test consisted of a continuous incremental protocol leading to volitional exhaustion. After a 2 min warm-up performed by the participants at 50 W, the exercise workload was increased by 25 W every 2 min until exhaustion. Participants were all verbally encouraged to achieve their maximal performance. The test was used to determine an individual workload for the aerobic exercise session (60% of maximal workload).

SESSION 3: RESISTANCE FITNESS TEST

After 30 min of rest, the participants performed a resistance exercise test. The test was used to determine a maximum of 15 repetitions (15-RM), which represents 60% of 1-RM (Fleck & Kraemer, 2014). The test was performed for six exercises: chest press, leg press, vertical traction, chest pull, leg extension, and shoulder press, using a Body-Solid EXM3000S multi-station gym machine. The procedure of this test was standardized, and was conducted by the same person for all participants. A 5 min rest period was given between the various exercise modes.

Cognitive Assessment

Cognitive function was evaluated by a computerized cognitive evaluation program, which included three tests: the Stroop test, the Go-NoGo test, and the Catch Game test (Mindstreams, NeuroTrax Corp., NJ, USA).

Participants were administered the tests in the same fixed order. Testing time was approximately 15 minutes. There were no rest periods between the three tests.

GO-NOGO TEST

A timed continuous performance test. The test measures components of attention and executive function, and also evaluates response time and response inhibition. The participants were presented with a series of large colored squares on a computer screen at variable sequences. Each square was one of four colors. The participants were instructed to respond as quickly as possible by pressing a computer mouse button if the square appeared in any color but red. This test included 30 trials. The variables measured included: accuracy, response time and its associated variance, a composite score computed as accuracy divided by response time, number of errors of omission, number of errors of commission, and response time associated with errors of commission. Omission errors are assumed to reflect deficient sustained attention or vigilance; commission errors - a combination of underlying processes, including impulsivity and inattention/memory deficit (Halperin, Wolf, Greenblatt, & Young, 1991).

STROOP TEST

A timed test of response inhibition and set shifting. The test measures cognitive functions related to attention and executive functions. This test was divided into three stages (levels):

Stage 1 (no interference stage): The participants were presented with a word in colored letters on a computer screen – the word did not name a color. Following a brief delay, the participants were presented with a pair of colored squares. They were instructed to choose as quickly as possible, by pressing a computer mouse button, the square that was the same color as the letters of the word presented. This stage included 10 trials.

Stage 2 (no interference stage): The participants were presented with a word on a computer screen that names a color in white letters. They were instructed to choose the color, by pressing a computer mouse button, from a list which represented the meaning of the word. This stage included 15 trials.

Stage 3: (with interference stage): Participants were presented with a word on a computer screen that names a color written with letters of a color other than that named by the word's meaning. They were instructed to choose, by pressing a computer mouse button, only the squares colored as presented by the letter's color. This stage included 15 trials.

Outcome parameters for each phase included accuracy, response time and its associated variance, and a composite score computed as accuracy divided by response time.

CATCH GAME TEST

This test measures motor planning involving hand-eye coordination and rapid responses. The test requires participants to catch a falling object on the computer screen by moving a paddle horizontally so that it can be positioned directly in the path of the falling object. This test included 20 trials. Outcome parameters included response time and associated variance for the first move, number of direction changes per trial, error for missed catches, and a total performance score.

These three cognitive tests are part of the Mindstreams (NeuroTrax Corp., NJ, USA) computerized battery that utilizes novel adaptations of traditional neuropsychological tests. Previous research has shown that these tests have good concurrent validity and reliability, and are highly correlated with performance on traditional neuropsychological batteries (Dwolatzky et al., 2003). This battery was already used with young, healthy adults (Doniger, Simon, & Schweiger, 2008). The battery is simple to use, requires no previous computer experience, and is web-based with a central database. All responses are made using either the computer mouse or the number pad on the keyboard.

Outcome Parameters

The outcome parameters include four scores: accuracy (number of correct responses); response time (RT); *SD* of RT; and, given the speed-accuracy tradeoff, a performance index, computed as (accuracy/RT) × 100, that is computed to assess performance in terms of both accuracy and response time.

The scores of the outcome parameters of the three tests are averaged to produce two summary scores, each indexing a different cognitive domain, as follows:

ATTENTION

Mean RTs for the Go-NoGo test and the no-interference (meaning) phase of the Stroop test, and mean *SD* of RT for the Go-NoGo test. These variables are related to attention, as rapid responses are an indication that the participant is on-task and therefore, appropriately attending to the stimuli.

EXECUTIVE FUNCTION

Performance indices for the Stroop test and the Go-NoGo test, and mean accuracy for the Catch Game test.

All outcome parameters were calculated automatically by using the custom software of the computerized Mindstreams battery test, and were blind to the treatment condition.

SESSIONS 2, 3, AND 4 (EXPERIMENTAL SESSIONS)

Laboratory visits 2, 3, and 4 were counter-balanced to minimize any order or learning effects. During these visits, the participants completed the cognitive tests prior to and immediately after (within 5 minutes) the experimental intervention condition, which consisted of a 30 min aerobic exercise session, a 30 min resistance exercise session, or a 30 min rest in a seated position, in a quiet room, for the control session.

AEROBIC CYCLE EXERCISE SESSION

This session began with a 3 min warm-up of pedaling with no load. The load was then increased until the participants reached their predetermined training load of 60% of maximal load, and they continued cycling for 30 min. This exercise session lasted approximately 40 min and could be described as a typical moderate-intensity aerobic exercise session, based on classifications proposed by the ACSM in 2010 (ACSM et al., 2010). The rated perceived exertion (RPE, Borg, 1974) for all participants during the aerobic session was in the range of 12-14. The scale ranges from 6 (*no exertion at all*) to 20 (*extremely hard exertion*).

RESISTANCE EXERCISE SESSION

This was designed to represent a typical moderate-intensity resistance exercise training session. The session began with a warm-up of stretching exercises. Then the participants performed the resistance exercises by completing three sets of 15 repetitions at 60% of their 1RM, for each of the six major muscle groups that were assessed in the first visit. The exercises were performed using a Body-Solid EXM3000S multi-station gym. Participants were given a 1 min rest between each set of 15 repetitions and prior to moving on to the next muscle group. At the end of this session, a 3 min cool-down was executed by walking slowly to the room were the cognitive tests were performed. This session lasted between 35-40 min.

CONTROL SESSION

During this condition, the participants sat quietly for 30 min.

Data Analysis

The statistical analysis consisted of two-way analyses of variance (ANOVAs) with repeated measures: 3 conditions (aerobic exercise, resistance exercise, control) × 2 times (pretest, post-test) were performed for each cognitive task. The required assumptions of normality for the parametric statistical procedure were met.

RESULTS

A significant treatment × time interaction was found for attention scores, $F(2, 37.85) = 3.2$, $p = .050$. A post-hoc test revealed a significant increase of attention scores following the resistance session (pre-post, $p = .016$). Figure 1 presents mean normalized scores of calculated attention test results before and after each intervention.

A significant treatment × time interaction was also found for EF scores, $F(2, 35.12) = 3.36$, $p = .046$. A post-hoc test revealed a statistically significant pre-post increase of EF scores after the resistance session, p = .026, as well as after the aerobic session, $p = .05$. Figure 2 presents means of EF scores before and after each intervention.

DISCUSSION

The purpose of the current study was to increase the available data on the acute effects of typical moderate resistance and aerobic exercise

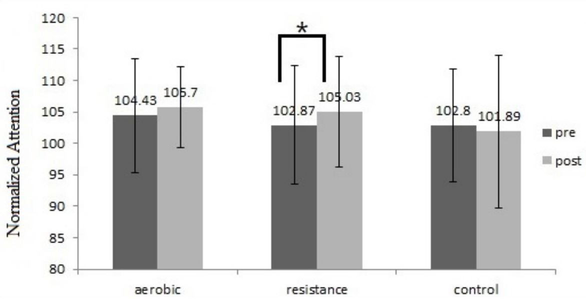

FIGURE 1.
Mean normalized scores of calculated attention before and after each intervention. * = Resistance, pre-post difference, $p = 0.16$.

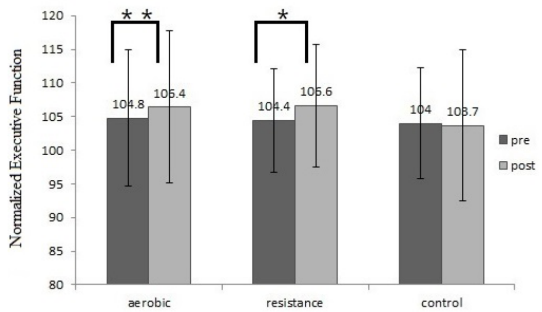

FIGURE 2.
Means of normalized executive function scores before and after each intervention. * = resistance session, pre-post difference, $p = .026$; ** = aerobic session, pre-post difference, $p = .05$.

TABLE 1.
Means of Normalized Attention and Executive Function Scores Before and After Intervention

	Aerobic		Resistance		Control	
	Pre	Post	Pre	Post	Pre	Post
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Attention	104.43±9.05	105.70±6.42	102.87±9.44	105.03±8.73	102.80±8.94	101.89±12.13
Executive function	104.8±10.1	106.4±11.3	104.4±7.7	106.6±9.1	104.0±8.2	103.7±11.3

sessions on cognitive function of young and healthy participants accustomed to physical exercise. Our main finding was that both resistance and aerobic exercise enhanced EF and attention in young healthy adults. Attention was significantly affected only by the resistance exercise session. Our results are in line with two studies, one conducted with middle aged women (Alves et al., 2012) and the other with high school students (Harveson et al., 2016), both of which demonstrated an improvement in EF following both aerobic and resistance exercise. The fact that acute aerobic exercise improves EF is well documented (e.g., Byun et al., 2014; Tam, 2013).

It is also interesting to note that, using a similar protocol but with a mixed group of middle-aged men and women, Dunsky et al. (2017) found increased scores of attention following an aerobic exercise session on a treadmill, but not after a strength session. They also found only marginally significant improvement in executive function scores following both aerobic exercise and resistance exercise sessions. However, Pontifex et al. (2009) did not observe improvements following acute resistance exercise. This may be attributed to the greater exercise intensity applied (80% of 1 RM), which resulted in a deterioration of the effect.

Johnson et al. (2016) compared the cognitive performance of older adults aged 71-72 years, using the Stroop test before and after an acute aerobic or resistance exercise session, and concluded that: "independent of mode or duration of exercise, the participants improved in the Stroop Inhibition task immediately post-exercise" (p. 2).

Resistance exercises were previously shown to increase plasma cortisol (Doma et al., 2015) and noradrenalin levels (Kliszczewicz et al., 2016). The effects of the increased sympathetic system may explain the positive effects of this exercise mode, in our study as well as in others (e.g., Chang, Ku et al., 2012; Chang, Tsai, Huang, Wang, & Chu, 2014).

Another possible mechanism that was suggested for the cognitive improvement following aerobic exercise is that exercise induces physical stress, activating both the sympathetic system and the hypothalamic pituitary-adrenal (HPA) axis (Mastorakos, Pavlatou, Diamanti-Kandarakis, & Chrousos, 2005). Stress hormones related to the activation of the HPA axis and the sympathetic system, such as cortisol and noradrenalin, respectively, were shown to affect cognitive function (Lambourne & Tomporowski, 2010; Segal, Cotman, & Cahill, 2012).

Referring specifically to attention, it should be noted that while the effect of aerobic exercise was only marginally significant in our study, the effect of resistance exercise was found to be clearly significant. To the best of our knowledge, this is the only study showing an effect of resistance exercise on attention outcomes in young, healthy participants. It should, however, be noted that attention shares some features with EF, in that most EF tasks also require attention (Strauss, Sherman, & Spreen, 2006). The present results indicate that indeed both acute aerobic and strength exercise sessions may positively enhance cognitive functions immediately post-exercise. However, the actual effects of an acute exercise bout on performance in life situations, such as taking a test in an academic setting or performing a demanding, novel manual task in a work setting, need further study. One of the relevant controls of such an investigation should be to practice the actual criterion task for the same duration as the acute exercise session before the testing. Also, the possible accumulative cognitive effects of repeated sessions of strength training, which result in established physiological and metabolic adaptations, need to be studied.

CONCLUSION

The present study indicates that an acute bout of a typical moderate-intensity resistance training session may positively influence cognitive functions in young, healthy participants. It is possible that adding strength training sessions to a chronic aerobic training program may enhance the cognitive benefits, but this should be tested in a suitable study design. The positive effects of resistance exercise on EF and attention may provide an additional incentive for practicing this type of exercise.

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CONFLICTS OF INTEREST

We declare no conflicts of interest including financial agreements or consultant relationships with organizations involved in the research.

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APPENDIX

TABLE A1.
Outcome Parameters of the Go-NoGo, Stroop, and Catch Game Tests from which Attention and Executive Function Scores were Calculated

	Aerobic				Resistance				Control			
	Pre		Post		Pre		Post		Pre		Post	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Attention	104.43	9.05	105.70	6.42	102.87	9.44	105.03	8.73	102.80	8.94	101.89	12.13
Executive function	104.8	10.1	106.4	11.3	104.4	7.7	106.6	9.1	104.0	8.2	103.7	11.3
Go-NoGo reaction time	102.74	10.55	104.76	8.23	101.61	9.91	103.65	8.85	102.15	10.58	100.31	13.75
Go-NoGo composite score	104.09	13.59	105.95	16.31	102.71	11.48	106.10	12.39	102.95	11.80	100.37	17.97
Go-NoGo omission errors	101.27	5.96	100.66	12.66	102.62	3.11	102.52	3.78	101.63	5.24	100.62	12.76
Go-NoGo commission errors	103.81	13.68	104.05	15.62	104.71	12.15	106.21	10.76	103.38	11.85	102.87	17.50
Go-NoGo commission response time	100.04	11.76	103.33	6.85	102.65	7.36	104.40	4.62	99.65	7.74	100.90	7.59
Stroop level 1 accuracy	104.34	.45	100.96	12.32	103.05	8.24	99.67	14.51	93.12	23.04	100.47	13.89
Stroop level 1, response time	111.55	8.61	113.67	7.28	110.78	11.07	112.80	8.65	111.64	9.74	111.90	9.82
Stroop level 1, SD	106.38	3.65	106.12	4.60	105.43	8.38	106.68	4.42	106.95	3.99	106.03	6.80
Stroop level 1, composite score	115.84	14.39	118.40	13.67	115.14	15.79	116.81	13.15	114.04	15.42	116.12	15.76
Stroop level 2, accuracy	96.30	20.31	101.52	11.50	97.61	16.88	100.63	13.97	102.55	10.11	101.10	11.41
Stroop level 2, response time	109.04	11.01	108.45	11.26	106.97	14.12	109.55	11.52	106.22	13.32	107.02	13.56
Stroop level 2, SD	104.43	10.09	103.50	11.28	103.70	12.63	103.70	13.15	101.05	16.18	102.45	13.11
Stroop level 2, composite score	109.95	15.47	110.24	13.88	108.04	15.77	112.01	15.96	107.94	14.78	108.77	14.26
Stroop level 3, accuracy	100.30	13.90	101.34	12.33	100.74	7.45	102.74	4.25	101.87	5.11	101.75	10.50
Stroop level 3, response time	103.89	12.97	105.30	13.85	105.35	4.83	106.61	5.46	104.59	7.03	103.40	13.98
Stroop level 3, SD	103.25	9.02	103.33	13.22	104.58	4.03	104.59	4.25	102.83	8.90	102.01	14.04
Stroop level 3, composite score	106.17	16.85	110.71	14.03	106.70	11.09	111.04	10.62	107.04	10.67	107.94	14.53
Catch game time to make first move	105.04	11.24	106.28	16.81	103.86	15.84	107.28	10.25	104.33	10.99	106.50	11.40
Catch game first move response time SD	100.95	11.57	102.59	16.79	101.00	15.25	101.53	13.10	100.66	10.46	101.47	12.64
Catch game average number of direction changes per trial	95.28	14.92	99.81	13.08	99.24	15.95	97.05	18.20	100.31	15.03	101.13	16.51
Catch game total score	104.20	10.30	102.40	14.11	103.92	11.07	102.70	12.76	101.93	11.39	102.93	10.49
Catch game average error on missed trials	103.24	8.72	103.21	11.21	103.50	9.46	102.36	11.28	102.77	9.19	102.91	8.94

MEASURED COGNITIVE PARAMETERS

AC10001: Accuracy

RT10001: Response Time

SD10001: Response Time Standard Deviation

CS10001: Composite Score

OE10001: Omission Errors

CE10001: Commission Errors

CR10001: Commission Response Time

AC10301: Accuracy, Level 1

RT10301: Response Time, Level 1

SD10301: Response Time Standard Deviation, Level 1

CS10301: Composite Score, Level 1

AC10302: Accuracy, Level 2

RT10302: Response Time, Level 2

SD10302: Response Time Standard Deviation, Level 2

CS10302: Composite Score, Level 2

AC10303: Accuracy, Level 3

RT10303: Response Time, Level 3

SD10303: Response Time Standard Deviation, Level 3

CS10303: Composite Score, Level 3

RD10303: Response Time Diff., Level 3 – 2

FM10700: Time to Make 1st Move

FS10700: First Move Response Time Standard Deviation

DC10700: Average Number of Direction Changes per Trial

TS10700: Total Score

ER10700: Average Error on Missed Trials