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Intensity and workload related dose-response effects of acute resistance exercise on domain-specific cognitive function and affective response – A four-armed randomized controlled crossover trial☆

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ABSTRACT

Introduction: Preliminary evidence indicates beneficial acute effects of resistance exercise on domain-specific cognitive function. Studies on dose response relationships and underlying mechanisms so far failed to deduce the impact of intensity and overall workload.

Objective: To analyze the impact of different intensities and workloads on effects of full body resistance training on cognitive attention, executive function performance, and affective response.

Methods: Twenty-six volunteers (9 (35%) female, age 25.9 ± 4.0 years) participated in three workload-matched (60%, 75% and 90% one repetition maximum intensity (1RM) resistance exercise interventions (RE)) and one workload reduced but intensity matched (75% 1RM, 50% overall workload) RE. Order was randomized, REs were on separate days with ≥48 h washout in between. Stroop Test performance (Attention: word and color condition; Interference control: word color interference), self-perceived levels of arousal and ability to concentrate were assessed before and after each RE.

Results: Workload-matched REs induced significant changes in attention and interference control. The workload reduced 75% 1RM RE induced changes in interference control, but no changes in attention performance. 75% 1RM exercise with full and 50% workload induced significant changes in arousal. Only 75% 1RM exercise with full workload significantly increased participants ability to concentrate. The repeated measures ANCOVA (Covariates: sex and fluid intelligence) indicated greater changes of interference control after 60% 1RM compared to 90% 1RM RE and greater changes of attention performance after 90% 1RM compared to 75% 1RM and 50% workload RE.

Discussion: Higher cognitive functions such as interference control seem to particularly benefit from moderate intensity RE whereas lower cognitive functions may be stimulated by higher intensity and higher workload RE. Self-perceived subjective factors did not mediate these dose response relationships. Future studies could analyze changes in cortisol levels, oxygenation, blood flow or electrophysiological signals to deduce triggers for increased stimulus-driven brain response and more controlled brain function.

1. Introduction

A growing body of literature report significant changes in domain specific cognitive functions after single bouts of exercise (Brisswalter, Collardeau, & René, 2002; Brush, Olson, Ehmann, Osovsky, & Alderman, 2016; Y. K.; Chang, Labban, Gapin, & Etnier, 2012; Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016; Tomporowski, 2003). The evidence for the effects of endurance exercise on cognitive performance is mounting (Brisswalter et al., 2002; Y. K.; Chang et al., 2012; Ludyga et al., 2016; Tomporowski, 2003). Like in other training situations and supported by a meta-analysis on endurance exercise, its specifics such as frequency, type, intensity or duration moderate the effects of physical training on cognitive functions {Chang et al., 2012 #2}. Evidence on the acute impact of resistance exercise and especially on the relevance of exercise characteristics including workload, intensity or duration is more limited.

Studies on acute effects of resistance exercise in young (H. Chang, Kim, Jung, & Kato, 2017; Johnson et al., 2016) and middle aged healthy participants (Alves et al., 2012; Y.-K.; Chang & Etnier, 2009a,b; Y.-K.; Chang, Ku, Tomporowski, Chen, & Huang, 2012; Y.-K.; Chang, Tsai,

☆ The research was conducted at the facilities of the Department of Sports Medicine.

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Huang, Wang, & Chu, 2014; Dunsky et al., 2017) analyzed lower cognitive functions such as attention and higher cognitive functions including executive functions and working memory. A large part of these studies applied the Stroop Test paradigm with the aim to deduce lower and higher cognitive functions based on comparable paradigms. Some of these studies reported effects on outcomes representing lower cognitive function solely (H. Chang et al., 2017; Y.-K. Chang & Etnier, 2009a). Others confirmed effects on lower and higher functions (Alves et al., 2012; Y.-K.; Chang et al., 2014) or on outcomes representing higher cognitive functions (Dunsky et al., 2017). Taken together, conflicting findings are reported, even in studies with comparable populations and study designs. One explanation for this phenomenon may be found in the fact that the characteristics of applied exercise regimes varied considerably between studies. Thus, the available data underlines the need to systematically analyze and differentiate the influence of factors such as intensity, workload or duration of exercise which might explain these contradictory results.

Some studies on resistance exercise already addressed this point and analyzed potential dose response relationships by comparing interventions with different intensity, duration and workload in crossover (Brush et al., 2016; Tsukamoto et al., 2017) or parallel group (Y.-K. Chang & Etnier, 2009b; Tsai et al., 2014) designs. The studies applied regimes with matched numbers of exercises, repetitions and sets whilst varying the weight or resistance. Consequently, the available evidence is based on designs comparing exercise regimes with different intensity and (based on varying intensity but same number of repetitions and sets) different volume and workload. The two available crossover studies reported a greater influence of exercise with higher intensity and workload on interference control performance, but not on working memory or cognitive flexibility in young adults (Brush et al., 2016; Tsukamoto et al., 2017). In contrast, the two available parallel group studies reported superior effects of moderate compared to higher intensity on executive functions (Y.-K. Chang & Etnier, 2009b) or no differences between the impact of higher and lower intensity (Tsai et al., 2014) on both lower and higher cognitive functions.

Taken together, the evidence on dose response relationships of single bouts of resistance exercise is far from sufficient and thus results in unanswered questions concerning the interaction of workload, duration and intensity. Evidence on exercise with an intensity over 100% of the ten repetition maximum (10RM), which can be considered equal to 75% of one repetition maximum (1RM) (Brush et al., 2016), is limited. One parallel group design study compared 40%, 70%, and 100% of 10RM intensity exercise (also varying in workload) and revealed an inverted u-shaped relation trend (Y.-K. Chang & Etnier, 2009b). Another study reported superior effects of intensities above 100% 10RM (80% 1RM) compared to lower intensity and workload (Tsukamoto et al., 2017). Based on these findings, future studies on dose response relationships need to delineate the effects of workload and intensity and include interventions with a broader range including intensities below and above the level of 100% of 10RM.

Likewise, more research is needed to elucidate the underlying mechanisms explaining intensity related alterations of resistance exercise effects. Previous studies hypothesized that enhanced cerebral neuronal activation and consequently the alteration of arousal might be a crucial mechanism for exercise induced changes of cognitive function (Tsukamoto et al., 2017). Changes in these and other psychological factors including self-perceived exertion, the ability to concentrate and affective response to exercise can be discussed as moderators for intensity related differences of exercise induced alterations of cognitive performance (Bloomer, 2005; Y.-K.; Chang & Etnier, 2009b; Tsukamoto et al., 2017). Consequently, further studies might include these potential moderators to clarify if the influence of intensity or workload on exercise induced alterations of lower and higher cognitive functions might be explained by increased alertness or affective response to exercise.

The aim of this study was to deduce the influence of intensity and workload on the acute effects of resistance exercise on domain specific cognitive performance. To analyze the influence of intensity we applied three exercise regimes with medium (75% 1RM which equals 100% 10 RM), high (90% 1RM) and low (60% 1RM) intensity. For all three interventions, we kept the amount of work done (physical workload) and the duration of the exercise sessions comparable. This was done by adapting the number of sets, repetitions and breaks between sets whilst using the same exercises and overall duration. To assess the influence of workload, we applied a fourth condition with medium intensity (75% 1RM) during which participants were asked to fulfill half the amount of work (50% workload). Since the Stroop Test was the most frequently applied paradigm in studies analyzing acute effects of resistance exercise and dose response relationships, we analyzed lower (attention) and higher cognitive function (executive function, inhibitory control) using this paradigm with the aim to facilitate direct comparison with earlier studies (Brush et al., 2016; Y. K.; Chang et al., 2012; Y.-K.; Chang & Etnier, 2009b; Tsukamoto et al., 2017). One secondary goal of our study was to analyze underlying mechanisms of intensity related alterations of resistance exercise effects on cognitive function. To reach this goal we included validated assessments for recently discussed moderators of resistance exercise effects including self-perceived affective response and exertion after exercise as well as exercise related changes of subjective level of arousal and the ability to concentrate (Bloomer, 2005; Y.-K.; Chang & Etnier, 2009b).

We hypothesized that 1) exercise intensity and workload are related to the effect on lower or higher cognitive function and that 2) changes in cognitive test performance induced by the applied regimes show significant differences. We furthermore assumed that 3) exercise induced changes in self-perceived arousal, ability concentrate, exertion or affective response differ between exercise regimes and that these differences might be related to changes in cognitive function.

2. Methods

2.1. Study design and setting

This study was designed as a four-armed randomized, controlled, crossover trial. The study was approved by the local ethics commission (reference number: 2017-36) and was conducted in accordance with the Declaration of Helsinki (Version Fortaleza 2012).

2.2. Participants

Participants (healthy, regularly active (by self-declaration) adult men and women) were recruited from a university campus and the surrounding community through the use of advertisement and flyers. We included young men and women (age mean ± standard deviation 25.9 ± 3.9 years). Exclusion criteria included acute or chronic physical and psychological diseases and drug abuse controlled by a questionnaire. Participants were asked to refrain from alcohol, caffeine and strenuous physical activity 24 h prior to the pre testing and all intervention appointments. The participants were also requested to maintain their regular physical activity habits and levels as well as their regular diet during participation in the study. Participants were defined as drop outs if they did not complete the pre-testing and all intervention appointments. Prior to study enrollment participants were informed about the benefits and risks of the investigation and afterwards signed an institutionally approved informed consent document to participate in the study.

2.3. Cognitive assessments

We applied a pen and paper version of the Stroop Test consisting of two congruent conditions assessing lower cognitive function and one incongruent condition assessing higher cognitive function. During the congruent conditions the participants were asked to 1) read out a list of color name words (red, blue, yellow, green) printed in black fond (Stroop I); and 2) to name the color in which a colored line is printed in (red, blue, yellow, green) (Stroop II). The inhibitory control condition (Stroop III) consisted of a list of the color words written in an incongruous color of ink (red, blue, yellow, green). Participants were asked to name the color in which the word was written (e.g. the word green written in red ink needed to be named as "red"). Lower cognitive function outcomes included attention and psychomotor speed. They were evaluated by time to completion [s] of both the Stroop Test congruent word reading (Stroop I) and the color naming condition (Stroop II) (Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006). We analyzed higher cognitive functions (executive function) by assessing interference control based on Stroop incongruent color word condition (Stroop III) time to completion [s] and interference score (Interference score = "Stroop III – [(Stroop I + Stroop II)/2]") (Van der Elst et al., 2006). Correct execution was supervised by an investigator and time to completion was measured using a stopwatch. Fluid intelligence was analyzed as confounder for cognitive performance changes and assessed using a self-administered Wiener Matrices Test (WMT) (Hornke, Küppers, & Etzel, 2000). The test consisted of 24 pictures each indicating seven symbols. Participants were asked to complete each picture by choosing a matching eight symbol out of a list. Main outcome measure was the number of correct matches. Participants were instructed to take as much time as needed and were informed that time to completion was not relevant for test performance.

2.4. Moderators of resistance exercise effects on cognitive function and confounders

Potential moderators of resistance exercise effects on cognitive functions were assessed via validated scales. Perceived exertion was assessed using a 15-point Borg scale ranging (Borg, 1982) and affective response was assessed using an 11-point Feeling Scale (Haile, Gallagher, & Robertson, 2015). Both assessments were applied immediately after exercise and participants were asked to rate mean perceived exertion and affective response during exercise. Intensity of arousal was assessed using a 6-point Felt Arousal Scale (Hardy & Rejeski, 1989; Svebak & Murgatroyd, 1985) whereas a 10 cm visual analog scale was applied to assess self-perceived ability to concentrate (Tsukamoto et al., 2017). Both factors were applied after pre and post testing and participants were asked to rate their arousal and ability to concentrate during cognitive testing.

To control the influence of habitual physical activity we used the short form of the International Physical Activity Questionnaire (IPAQ) and analyzed as Metabolic Equivalent of Task (MET) hours per week (METh/wk) (Hagströmer, Oja, & Sjöström, 2006).

2.5. Strength assessment and resistance exercise regimes

Participants' 1RM was assessed for six exercises (chest press, leg press, latissimus pull down, seated rowing, seated squat, and shoulder press) adopting the following 1RM prediction method: 1RM = 100*weight lifted/(102,78 - 2,78 * number of repetitions performed) (Brzycki, 1993). Based on this approach 100% of ten repetition maximum relates to 75% of one repetition maximum. This approach was applied by earlier studies (Dunsky et al., 2017) and is reported to be strongly associated with the directly assessed 1RM (Pereira & Gomes, 2003).

All participants executed four different exercise regimes in a randomized order and a ≥48 h wash-out time in-between was hold. Randomization (block-randomization, two blocks, each block n = 24, permutated order, one complete block, one with n = 2 participants) was undertaken using a randomization software (https://www.randomizer.org/; Copyright © 1997–2018 by Geoffrey C. Urbaniak and Scott Plous). Three exercise regimes varied in intensity but were matched in workload for each exercise: 1) Two sets of 19 repetitions with 60% of 1RM; 2) Three sets of 10 repetitions with 75% of 1RM; and 3) Five sets of five repetitions with 90% 1RM. All three regimes demanded the participants to perform a comparable amount of physical work and hence were described as workload matched. The fourth regime applied an intensity of 75% of 1RM and the same exercises but half the physical work using three sets of five repetitions and hence was described as workload reduced. During all appointments, the exercises were conducted in the same order (chest press, leg press, latissimus pull down, seated rowing, seated squat, and shoulder press). Participants were asked to execute the exercises with the same pace and range of motion during all repetitions of all exercise regimes. Resting intervals during session were adjusted individually to reach a duration of approximately 60 min for all exercise regimes.

2.6. Appointments

Participants visited our facility on five separate days. During the first appointment, anthropometric data, physical activity behavior, fluid intelligence and educational status were assessed. Furthermore, participants were familiarized with the cognitive tasks and the scales for perceived exertion, affective response, intensity of arousal and perceived concentration/attention. Afterwards, participants performed a warm up (2 min jumping jacks), were familiarized with the exercises and tests and we assessed their 1RM for all exercises.

Resistance exercise appointments started with cognitive testing. After completing all tests, participants reported their perceived intensity of arousal and self-perceived ability to concentrate during cognitive testing. Thereafter, participants performed a 2 min warm up and started the exercise session. After all exercises' completion, overall duration of the session was noted and participants rated their mean perceived exertion and affective response for the whole session. Immediately after the exercise session, participants underwent cognitive testing. Again, they afterwards indicated the intensity of arousal and self-perceived ability to concentrate during cognitive testing.

All appointments were executed at a comparable time of day. Cognitive data was assessed in the same standardized setting during appointments (room size, workplace, temperature, and lighting) to minimize distracting stimuli.

2.7. Data analysis and power calculations

For statistical analysis, we used Microsoft Excel 2010 and SPSS Version 24 (IBM Corp., Armonk, NY, USA). We performed a sample size calculation (G*power, Version 3.1.9.2, Germany) (Faul, Erdfelder, Lang, & Buchner, 2007) a priori based on the data of Brush and colleagues who applied the Stroop Test in a comparable setting and were able to report moderate to large effect sizes for Stroop Test outcomes including reaction times and interference score (Brush et al., 2016). We calculated the sample size for the hypothesis that exercise intensity and workload were related to the effect on domain specific cognitive function. We tested this hypothesis by repeated measures ANOVAs analyzing the effect of exercise regimes on lower and higher cognitive functions. Using an estimated moderate effect size of $eta^2 = 0.1$, a Bonferroni adjusted alpha of .025 we calculated a sample size of minimum 24 participants for repeated measurements ANOVAs with one within factor (four conditions) and no between subject factor (one group).

Descriptive statistics were reported as means with standard deviations. Differences between male and female participants in baseline data including height, weight, age, education, fluid intelligence and habitual physical activity were analyzed using multiple T-tests for non-homogenous variances. The 95% confidence intervals of post to pre differences were calculated to detect significant exercise induced changes of self-perceived level of arousal and ability to concentrate as well as significant changes of Stroop Test performance. Wilks-Lambda multivariate test for non-homogeneous variances was applied to compare the test duration between all four interventions. ANOVAs with repeated measures (four exercise regimes) were applied to analyze the effect of workload and intensity on exertion and affective response to exercise and on changes in self-perceived arousal and the ability to concentrate. In case of significant changes in self-perceived arousal and ability to concentrate partial correlation analysis, controlled for sex and fluid intelligence, was applied to investigate associations between exercise induced changes in these factors and cognitive outcomes. Furthermore, the association of affective response and exertion after exercise with exercise induced changes in cognitive outcomes was analyzed using partial correlation analysis controlled for sex and fluid intelligence. ANCOVAs with repeated measures (four exercise regimes) controlled for sex and fluid intelligence were applied to identify effects of workload and intensity on changes in task specific cognitive performance. In case of significant effects of intensity or workload, post hoc pairwise comparisons of estimated marginal means were applied. In case of significant effects of intensity follow-up trend analyses for linear and cubic trends were applied. A p-value ≤ 0.05 was considered as statistically significant. P values ≤ 0.1 were considered as significant trend. We reported degrees of freedom, F values and effect sizes using partial eta squared ($\eta 2p$) with 0.01–0.059, 0.06–0.139, and greater than 0.14 representing small, moderate, and large effects (Cohen, 1973).

3. Results

3.1. Descriptive data

All twenty-six participants completed all exercise regimes. Anthropometric data, educational level, fluid intelligence and habitual physical activity levels of included female and male participants and the overall sample are presented in table 1. Females showed significantly lower height ($T = -2.9$; $p = 0.013$) and weight ($T = -2.4$; $p = 0.031$) compared to males.

3.2. Influence of exercise intensity and workload on self-perceived exertion and affective response to resistance exercise

Table 2 shows descriptive data for exercise duration, perceived exertion and affective response. No significant effect of exercise regimes on exercise duration were found ($F(3) = 2.756$; $p = 0.065$; $\eta 2p = 0.264$). Figure 1 indicates 95% confidence intervals of perceived exertion and affective response after all four interventions. Repeated measures ANOVA indicated significant effects of exercise regimes on perceived exertion after exercise ($F(3) = 31.111$; $p = 0.001$; $\eta 2p = 0.554$). Post hoc pairwise comparisons revealed significantly lower perceived exertion after 75% 1RM intensity with 50% workload compared to exercise with 60% 1RM ($p < 0.01$), 75% 1RM ($p < 0.01$) and 90% 1RM ($p < 0.01$) intensity (see Fig. 1). Post hoc testing indicated no differences of perceived exertion after exercise for regimes with different intensity but comparable workload. Repeated measures ANOVA revealed no effects of exercise regimes on affective response to exercise ($F(3) = 2.648$; $p = 0.055$; $\eta 2p = 0.096$).

3.3. Effects of resistance exercise and influence of exercise intensity and workload on self-perceived state of arousal and ability to concentrate

Figure 1 shows 95% confidence intervals of subject´s state of arousal and self-perceived ability to concentrate indicated as difference of post intervention to pre intervention values. Pre intervention values of state of arousal ($F(3) = 1.772$; $p = 0.161$; $\eta 2p = 0.066$) and self-perceived ability to concentrate ($F(3) = 1.513$; $p = 0.224$; $\eta 2p = 0.057$) were not different between the four exercise conditions. As indicated by the 95% confidence intervals in figure 1, resistance exercise with an intensity of 75% 1RM with 100% workload and with 50% workload both led to significantly increased state of arousal. However, repeated measures ANOVA revealed no significant effects of exercise regimes on changes of state of arousal ($F(3) = 0.790$; $p = 0.503$; $\eta 2p = 0.031$). As indicated in figure 1, self-perceived ability to concentrate was significantly altered solely after 75% 1RM exercise with 100% workload. No significant effects of exercise regimes on change of self-perceived ability to concentrate were found ($F(3) = 1.849$; $p = 0.146$; $\eta 2p = 0.069$) using repeated measures ANOVA.

3.4. Effects of resistance exercise and influence of exercise intensity and workload on lower and higher cognitive function

Figure 2 shows changes of Stroop Test I, II, III and Stroop Interference Score from before interventions (pre) to after interventions (post) indicated as 95% confidence intervals of post to pre differences. Significant exercise related changes of Stroop I and Stroop II performance occurred after all workload matched interventions (60%, 75% and 90% 1RM) but not after resistance exercise with reduced workload (75% 1RM 50% workload). Stroop III and Stroop Interference Score were increased after all interventions.

Repeated measures ANCOVAs revealed no effects of exercise regimes on post to pre changes of Stroop I ($F(3) = 0.936$; $p = 0.428$; $\eta 2p = 0.039$) and Stroop III ($F(3) = 1.779$; $p = 0.159$; $\eta 2p = 0.072$) performance.

Repeated measures ANCOVAs indicated significant effects of exercise regimes on Stroop Test II ($F(3) = 2.722$; $p = 0.051$; $\eta 2p = 0.106$) and Stroop Interference Score performance changes ($F(3) = 3.147$; $p = 0.030$; $\eta 2p = 0.120$). Post hoc pairwise comparisons of estimated marginal means for Stroop Test II revealed a trend for larger effects of the 90% intensity exercise intervention compared to the 75% intensity exercise with 50% reduced workload ($p = 0.10$). Therefore, we conclude a mixed effect of workload and intensity of resistance exercise on Stroop Test II performance. Post hoc pairwise comparisons of estimated marginal means for Stroop Interference Score performance indicated a significant effect of exercise intensity based on significantly greater post to pre changes for the 60% 1RM intensity exercise compared to the 90% 1RM intensity exercise ($p = 0.037$). Furthermore, trend analysis revealed a significant linear trend ($F(1) = 5.517$; $p = 0.027$; $\eta 2p = 0.181$) indicating larger beneficial effects on Stroop Interference Score performance for lower intensity resistance exercise.

Table 1
Anthropometrics, educational level (1 = lower school certificate, 2 = apprenticeship or technical baccalaureate, 3 = High school degree, 4 = University degree), fluid intelligence testing and habitual physical activity using the IPAQ questionnaire. * indicates significant differences between sexes ($p \leq 0.05$). METh/wk = Metabolic equivalent of task hours per week; n = number; WMT = Wiener Matrices Test.

Outcome	Female (n = 9)	Male (n = 17)	Overall (n = 26)
Age in years	25.7 ± 5.0 (18–36)	26.0 ± 3.5 (18–32)	25.9 ± 4.0 (18–36)
Height in centimeters	168.3 ± 9.2 (151–179) *	178.2 ± 5.7 (165–185)	174.8 ± 8.4 (151–185)
Weight in kilograms	67.0 ± 14.6 (51–100) *	80.8 ± 12.8 (60–101)	76.0 ± 14.7 (51–101)
Education level	3.4 ± 0.9 (2–4)	3.1 ± 1.1 (1–4)	3.2 ± 1.0 (1–4)
Fluid intelligence as WMT points	14.0 ± 3.3 (8–18)	11.6 ± 3.1 (6–18)	12.4 ± 3.3 (6–18)
Physical activity as METh/wk	46.7 ± 49.1 (0–140)	84.9 ± 63.1 (13–221)	71.7 ± 60.6 (0–221)

Table 2
Descriptive data of intervention duration, perceived exertion during and affective response to exercise indicated as mean ± standard deviation.

Outcome	Exercise intervention			
Mean ± standard deviation	60% 1RM	75% 1RM	90% 1RM	75% 1RM and 50% Workload
Duration (minutes)	58.35 ± 2.90	59.42 ± 1.21	60.65 ± 3.10	57.27 ± 3.84
Perceived exertion (15-point Borg Scale)	16.15 ± 2.05	15.69 ± 1.72	15.65 ± 2.02	13.15 ± 2.17
Affective response (11-point Feeling Scale)	3.77 ± 2.51	3.50 ± 3.06	4.15 ± 2.95	4.27 ± 2.81

3.5. Associations of exercise induced changes of self-perceived state of arousal, ability to concentrate, exertion and affective response with exercise induced changes in cognitive performance

As indicated in figure 1, solely exercise with 75% 1RM intensity was feasible to induce significant changes in self-perceived state of arousal and ability to concentrate (see Table 3). Consequently, correlation analysis for associations between moderators and changes in cognitive performance was conducted for the effects of 75% 1RM intensity exercise. An overview of the results including r and p values is given in table 4. Changes in the level of arousal after exercise were significantly related to changes in Stroop Test II performance. Affective response to exercise was significantly associated with changes in Stroop Test III and Stroop Interference Score performance. Comparing the results of ANOVA and ANCOVA analyses for affective response markers and cognitive outcomes, we were not able to detect comparable dose-response relationships indicating moderating effects of affective response on intensity or workload related differences in cognitive performance adaptations.

4. Discussion

This study was designed to analyze the intensity and workload related dose-response effects of acute resistance exercise on domain specific cognitive function. Exercise intensity showed a negative association with changes in Stroop Interference Score indicating a larger effect of lower intensity resistance exercise on higher cognitive functions. Comparable effects of exercise interventions with matched overall workload independent of exercise intensity on lower cognitive functions occurred. In contrast, an exercise with reduced workload led to improved higher cognitive function but not attention performance (lower cognitive function) and thus indicates that exercise effects on lower cognitive functions seem to be related to workload. The second aim of this study was to analyze the relevance of affective response for exercise induced changes in cognitive performance. We were able to confirm the association of higher self-perceived arousal with beneficial adaptations of lower cognitive functions. Furthermore, we detected an association of a more positive state of mind after exercise with increased higher cognitive functions. However, affective response was not associated to intensity or workload related dose-response relationships of exercise effects on higher or lower cognitive function.

4.1. Intensity and workload dependent dose-response relationships for lower cognitive function adaptations

We conducted two repeated measures ANCOVAs analyzing markers for cognitive attention performance and detected a trend for larger effects of high intensity resistance exercise compared to a regime with lower intensity and lower workload. Thus, our data confirms that beneficial effects on lower cognitive functions rely on a sufficient combination of both workload and intensity. These findings are in line with earlier studies on mixed dose response relationships reporting greater beneficial effects of resistance exercise with medium to high intensity and high workload compared to regimes with lower intensity and lower workload (Y.-K. Chang & Etnier, 2009b) or to endurance exercise (H. Chang et al., 2017). Leading to the same direction and indicating lower limits for duration of sufficient moderate intensity (60% 1RM intensity) resistance exercise, regimes ranging from 10 to 30 min showed no effect on Stroop Test based markers of attention performance (Johnson et al., 2016). However, both exercise regimes showed an impact on higher cognitive functions (Johnson et al., 2016). Contrastingly, a study with a rather short intervention time of 17 min compared high and low intensity exercise and was able to report a beneficial influences of intensity on Stroop Test based markers of lower cognitive functions (Tsukamoto et al., 2017) and thus confirms the interaction of workload and intensity. Taken together, we might

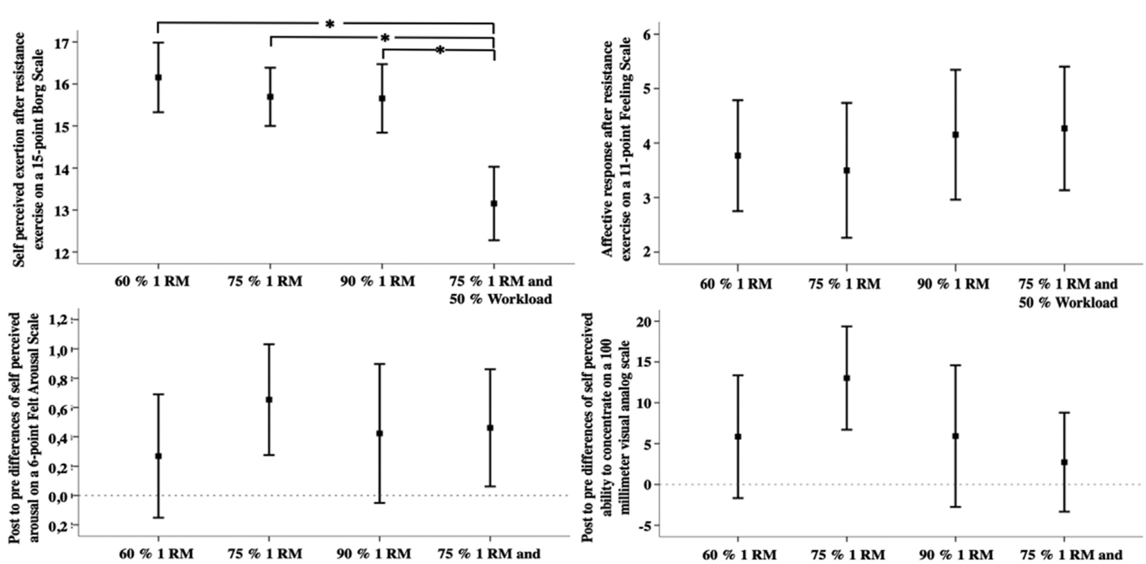

Figure 1. Means and 95% confidence intervals of perceived exertion as well as affective response after resistance exercise and acute resistance exercise effects on self-perceived state of arousal and ability to concentrate. * indicates significant differences ($p \leq 0.05$).

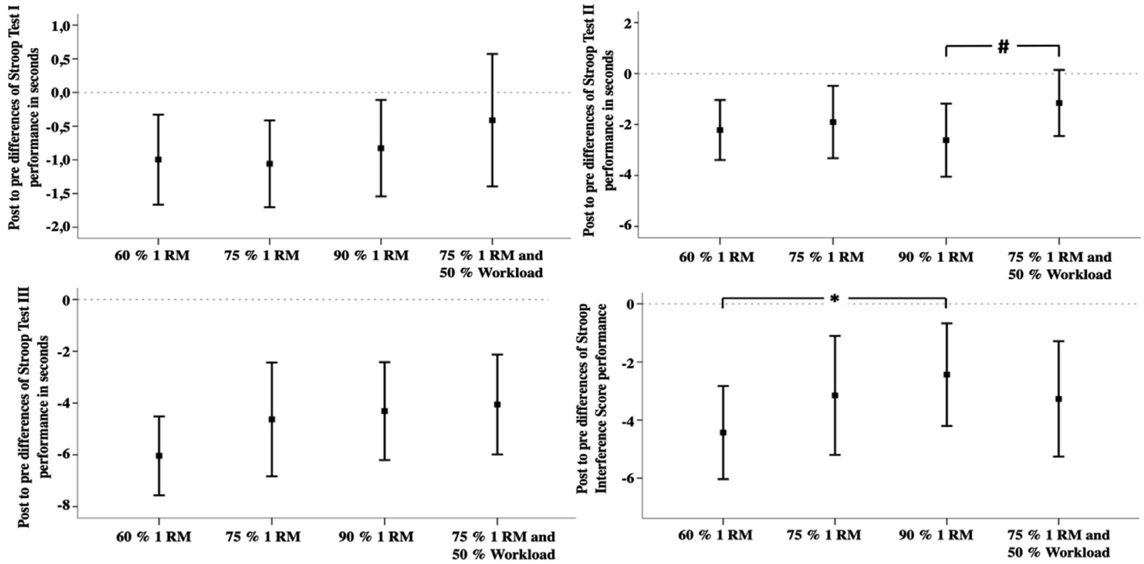

Figure 2. Means and 95% confidence intervals of post to pre differences of Stroop Test performance analyzed as Stroop congruent word (Stroop Test I), congruent color (Stroop Test II), incongruent color word (Stroop Test III) and Stroop interference score. * indicates significant differences (p ≤ 0.05) and # indicates statistical trends (p ≤ 0.1).

Table 3
Descriptive data of intervention effects on intensity of arousal, self-perceived ability to concentrate and Stroop Test outcomes including congruent word (Stroop Test I), congruent color (Stroop Test II), incongruent color word (Stroop Test III) time to completion and Stroop interference score. Data is indicated as mean ± standard deviation of before intervention values (pre), after intervention values (post) and post to pre differences.

Outcome	Intervention	Before	After	Post to pre difference
Intensity of arousal (6-point Felt Arousal Scale)	60% 1RM	3.9 ± 1.3	4.1 ± 1.1	.3 ± 1.0
	75% 1RM	3.8 ± 1.1	4.5 ± .8	.7 ± .9
	90% 1RM	3.9 ± 1.2	4.3 ± 1.1	.4 ± 1.2
	75% 1RM and 50% Workload	3.8 ± 1.3	4.2 ± 1.3	.5 ± 1.0
Self-perceived ability to concentrate (10 cm visual analog scale)	60% 1RM	5.8 ± 2.4	6.4 ± 2.1	.6 ± 1.9
	75% 1RM	5.5 ± 1.9	6.8 ± 1.7	1.3 ± 1.6
	90% 1RM	5.9 ± 2.4	6.5 ± 2.4	.6 ± 2.2
	75% 1RM and 50% Workload	5.8 ± 2.0	6.1 ± 2.2	.3 ± 1.5
Stroop Test I	60% 1RM	25.9 ± 3.2	24.9 ± 3.4	−1.0 ± 1.7
	75% 1RM	25.6 ± 2.9	24.5 ± 2.9	−1.1 ± 1.6
	90% 1RM	25.5 ± 2.7	24.7 ± 2.9	-.8 ± 1.8
	75% 1RM and 50% Workload	25.5 ± 2.4	25.1 ± 3.6	-.4 ± 2.4
Stroop Test II	60% 1RM	35.6 ± 2.9	33.4 ± 2.9	−2.2 ± 2.9
	75% 1RM	36.3 ± 4.3	34.4 ± 2.9	−1.9 ± 3.5
	90% 1RM	36.6 ± 3.5	34.0 ± 3.0	−2.6 ± 3.5
	75% 1RM and 50% Workload	35.9 ± 3.5	34.7 ± 4.4	−1.2 ± 3.2
Stroop Test III	60% 1RM	57.7 ± 9.5	51.6 ± 8.8	−6.0 ± 3.8
	75% 1RM	57.4 ± 11.0	52.7 ± 9.1	−4.6 ± 5.5
	90% 1RM	59.1 ± 7.7	54.8 ± 9.1	−4.3 ± 4.7
	75% 1RM and 50% Workload	58.0 ± 11.5	53.9 ± 10.6	−4.1 ± 4.8
Stroop Interference Score	60% 1RM	26.9 ± 8.6	22.5 ± 8.5	−4.4 ± 4.0
	75% 1RM	26.4 ± 9.2	23.2 ± 8.1	−3.2 ± 5.1
	90% 1RM	27.9 ± 8.1	25.5 ± 8.0	−2.4 ± 4.4
	75% 1RM and 50% Workload	27.3 ± 10.8	24.0 ± 9.5	−3.3 ± 4.9

conclude that lower cognitive functions such as attention might benefit more from both higher intensity and higher workload resistance exercise. Based on our findings a lower limit for overall workload in resistance exercise regimes with six whole body exercises might occur between two sets of 19 repetitions with 60% of 1RM intensity and three sets of five repetitions with 75% 1RM intensity. Although we were able to confirm beneficial effects of lower intensity resistance exercise, higher intensity seems to be more effective and future studies on the optimal or minimal effective dose thus should further analyze how effects of high intensity (90% 1RM) resistance exercise on lower cognitive functions such as attention are influenced by exercise workload or exercise duration.

4.2. Intensity and workload dependent dose-response relationships for higher cognitive function adaptations

Our results for Stroop Interference Score lead to the conclusion that lower intensity resistance exercise (60% 1RM) leads to larger beneficial effects on higher cognitive functions compared to intensities ≥ 75% 1RM. Our data furthermore indicates that this inverse dose response relationship for exercise induced beneficial changes of interference control seems to be unaffected by the applied overall workload. Combining our data and those of earlier studies, we hypothesize that this inverse relationship might have a lower limit. Our design with considerably higher maximal intensity (90% 1RM) extends preliminary evidence focusing low to moderate intensity and indicating larger beneficial effects of moderate intensity resistance exercise ranging

Table 4

Partial correlation analysis, controlled for sex and fluid intelligence, of exercise induced changes of self-perceived state of arousal and ability to concentrate as well as exercise induced exertion and affective response with exercise induced changes in cognitive performance including congruent word (Stroop Test I), congruent color (Stroop Test II), incongruent color word (Stroop Test III) time to completion and Stroop interference score. Data is indicated as correlation coefficient r and p values. * indicates significant differences ($p \leq 0.05$).

Outcome	Stroop Test I	Stroop Test II	Stroop Test III	Stroop Interference Score
Intensity of arousal (6-point Felt Arousal Scale)	$r = 0.011$ $p = 0.958$	$r = -0.409$ $p = 0.047$ *	$r = -0.268$ $p = 0.205$	$r = -0.141$ $p = 0.511$
Self-perceived ability to concentrate (10 cm visual analog scale)	$r = -0.111$ $p = 0.604$	$r = -0.127$ $p = 0.553$	$r = 0.231$ $p = 0.277$	$r = 0.312$ $p = 0.137$
Perceived exertion (15-point Borg Scale)	$r = -0.348$ $p = 0.096$	$r = 0.224$ $p = 0.293$	$r = 0.137$ $p = 0.522$	$r = 0.125$ $p = 0.561$
Affective response (11-point Feeling Scale)	$r = 0.133$ $p = 0.536$	$r = -0.086$ $p = 0.691$	$r = -0.502$ $p = 0.012$ *	$r = -0.528$ $p = 0.008$ *

between 80% 1RM (Tsukamoto et al., 2017), 100% 10RM (Brush et al., 2016) and 70% 10RM (Y.-K. Chang & Etnier, 2009b) compared to considerably lower intensities (≤40% 1RM) with unmatched workload. In line with studies focusing the mixed effect of duration and workload who report a beneficial impact of 10–17 min of resistance exercise on higher cognitive functions (Johnson et al., 2016; Tsukamoto et al., 2017) we were not able to detect a lower limit for workload. In a synopsis of our data on high to moderate intensity resistance exercise and the results of earlier studies on the lower intensity spectrum, the available evidence leaves room to speculate on a possible inverted U-shaped relationship with a sweet spot for maximal effects within an intensity spectrum below 75% and above 40% 1RM intensity.

4.3. The relevance of affective response, self-perceived state of arousal, ability to concentrate and for exercise induced adaptations in higher and lower cognitive functions

The secondary goal of our study was to analyze the relevance of recently discussed psychological moderators of resistance exercise effects for intensity and workload dependent dose-response relationships. Self-perceived exertion after exercise was associated with workload but not intensity. This indicates less exertion after exercise with reduced workload and comparable duration. Since the exercise with reduced workload was the only regime showing no significant effect on congruent Stroop Test conditions, it might be hypothesized that exertion is a moderator for exercise effects on lower cognitive functions. This is in line with earlier studies suggesting that affective response to exercise, such as higher rate of perceived exertion, is linked to enhanced neuronal activity during isometric muscle contraction (Berchicci, Menotti, Macaluso, & Di Russo, 2013) and therefore might lead to adaptations in cognitive performance. We thus confirm the results of earlier studies analyzing combined effects of workload and intensity (Bloomer, 2005; Y.-K.; Chang & Etnier, 2009b; Tsukamoto et al., 2017) and hypothesize that the dose response relationships reported in this studies might be moderated by workload alterations rather than variations of intensity. However, it is important to underline that we found no linear relation supporting the relevance of self-perceived exertion for cognitive performance adaptations.

Further markers for affective response including exercise related changes of self-perceived ability to concentrate and arousal were not significantly related to intensity or workload. However, since significant alterations of arousal and ability to concentrate occurred solely after 75% 1RM intensity exercise, a trend for intensity related effects could be discussed. Further analyzing this exercise regime, we were able to provide evidence for a moderating effect of affective response indicating that a more positive psychological state (Haile et al., 2015) is connected to better performance of higher cognitive functions. Lower cognitive functions were not associated with changes in this marker but with higher levels of self-perceived arousal after exercise (Hardy & Rejeski, 1989; Svebak & Murgatroyd, 1985). Confirming our results on lower cognitive function, a meta-analysis on endurance exercise reported that exercise-induced arousal might enhance performance of tasks that involve rapid decisions and automatized behaviors and furthermore is likely to facilitate the speed of mental processes and to enhance memory storage and retrieval (Lambourne & Tomporowski, 2010). Based on our data we extend current evidence by the fact that higher cognitive functions seem to benefit from changes in psychological state of mind and positive thinking rather than from increased arousal.

4.4. Mechanisms for intensity and workload dependent dose response relationships and the influence of affective response

One of the most frequently discussed mechanisms behind the favorable effects of low to moderate intensity exercise on higher cognitive functions is the alteration of neuronal tissue oxygenation. Chang and colleagues analyzed this mechanism in the context of resistance exercise and report an association between worse cognitive performance and decreased oxygenation in the prefrontal cortex during high-intensity exercise compared with moderate-intensity exercise (H. Chang et al., 2017). Based on these findings they hypothesize that moderate exercise intensity induces better oxygen and nutrient distribution by increased blood flow and oxygen saturation (H. Chang et al., 2017). However, such alterations could influence both lower and higher cognitive functions. Therefore, the question arises which other pathways might explain the specific effects of intensity and workload on higher and lower cognitive functions.

A potential mechanism for specific effects could be based on alterations of hormone levels. Tsai and colleagues report lower concentrations of the stress hormone cortisol and higher concentrations of growth hormone and insulin like growth factor 1 after moderate and high intensity resistance exercise (Tsai et al., 2014). However, the lowering effect on stress hormone level is indicated to be less pronounced and the stimulation of factors for neurogenesis seem to be higher after high intensity exercise (Tsai et al., 2014). As the workgroup points out, decreased cortisol might shift the brain from a stimulus-driven response mode during stressful situations to a more controlled mode (Tsai et al., 2014). In line with our data on affective response and arousal it could be hypothesized that the execution of higher cognitive functions might benefit from adaptations favoring a more controlled mode. In contrast, a more stimulus driven brain functioning, induced by high intensity exercise and based on higher cortisol levels, could increase arousal and might be more advantageous for lower cognitive function performance.

Further studies need to analyze the interaction of physiological and neuropsychological responses in order to understand and differentiate the impact of increased cardiovascular function, hormonal levels, cerebral neuronal activation and subjective factors like arousal or motivation. These studies furthermore should include objective outcomes for changes in cognitive performance such as electroencephalographic markers including event related potentials and readiness potentials, functional magnetic resonance imaging or spectroscopy.

4.5. Strengths and limitations

Our design aimed at analyzing the influence of intensity and workload by using four different exercise regimes. To reach this goal we matched the amount of work within three sessions and included one session with half the amount of work. In order to control additional factors, we matched the overall duration, the exercises and the time of enrollment for all interventions. Consequently, the resting time between sessions varied between interventions and thus might have influenced differences in perceived exertion. A strength of this study is the assessment of cognitive performance and subjective factors during pre and post measurements in order to eliminate the influence of baseline differences. Extending the findings of earlier studies reporting arousal levels solely after exercise (Tsukamoto et al., 2017) or as mean value during exercise (Y.-K. Chang & Etnier, 2009b), we were able to demonstrate that changes of cognitive performance were associated with changes in levels of arousal and affective response to exercise whereas the self-perceived ability to concentrate and exertion after exercise showed no impact on cognitive performance adaptations. A limitation of our study design is the number of trial conditions. Based on our analysis we were able to report preliminary evidence for the interaction of workload and intensity. However, future studies are needed to further analyze the impact of exercise duration and workload on the effect of a high intensity resistance intervention on lower cognitive function. Since we applied just one cognitive test for lower and higher cognitive function, another approach for future studies would be to include more sensitive cognitive function testing combined with objective markers for neuropsychological activation such as EEG based event related potential analysis.

4.6. Practical application and conclusion

Endurance and resistance exercise seem to impact domain specific cognitive functions in a comparable manner. We thus adopt the inverse U-shaped dose response relationship reported by Chang and colleagues for endurance exercise (Y. K. Chang et al., 2012) and confirm that higher cognitive functions such as executive function are improved more after medium-intensity resistance exercise than after higher-intensity exercise. Furthermore, these adaptations appear to be related to a more positive affective response to exercise. Based on these findings, acute resistance exercise with moderate intensity and rather short duration and low workload could be of use in occupational or academic settings. Contrastingly, high intensity exercise with higher volume might be more suited to increase alertness, attention and the ability to perform lower cognitive functions. Future studies could analyze the application as a pre-activation in settings demanding this more stimulus driven response mode. In addition to the well-known effects on overall health, information on specific beneficial effects on work- and study-related abilities like cognitive flexibility may foster the acceptance and application of active breaks during sedentary work. To further analyze the setting specific feasibility, future studies need to focus the optimal duration of such interventions and the sustainability in terms of repeatability and delayed or long-term effects.

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