©Journal of Sports Science and Medicine (2021) **20**, 391-397
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2021.391

Research article

Acute Effects of High-intensity Resistance Exercise on Cognitive Function

John Paul V. Anders [1,2], William J. Kraemer [1]✉, Robert U. Newton [3], Emily M. Post [4], Lydia K. Caldwell [5], Matthew K. Beeler [6], William H. DuPont [7], Emily R. Martini [1], Jeff S. Volek [1], Keijo Häkkinen [8], Carl M. Maresh [1] and Scott M. Hayes [9,10]

[1] Department of Human Sciences, The Ohio State University, Columbus, OH, USA; [2] Department of Education and Human Sciences, University of Nebraska-Lincoln, Lincoln, Nebraska, USA; [3] Exercise Medicine Research Institute, Edith Cowan University, Joondalup WA 6027, Australia; [4] Exercise Science Department, Ohio Dominican, Columbus, Ohio, USA; [5] Applied Physiology Laboratory, University of North Texas, Denton, TX, USA; [6] Department of Exercise Science, Hastings College, Hastings, NE, USA; [7] Department of Biomedical Sciences, Quinnipiac University, Hamden, CT, USA; [8] Department of Biology of Physical Activity & Neuromuscular Research Center, University of Jyväskylä, Jyväskylä, Finland; [9] Department of Psychology, The Ohio State University, Columbus, OH, USA; [10] Chronic Brain Injury Initiative, The Ohio State University, Columbus, OH, USA

Abstract

The purpose of the present study was to examine the influence of an acute bout of high-intensity resistance exercise on measures of cognitive function. Ten men (Mean ± SD: age = 24.4 ± 3.2 yrs; body mass = 85.7 ± 11.8 kg; height = 1.78 ± 0.08 m; 1 repetition maximum (1RM) = 139.0 ± 24.1 kg) gave informed consent and performed a high-intensity 6 sets of 10 repetitions of barbell back squat exercise at 80% 1RM with 2 minutes rest between sets. The Automated Neuropsychological Assessment Metrics (ANAM) was completed to assess various cognitive domains during the familiarization period, immediately before, and immediately after the high-intensity resistance exercise bout. The repeated measures ANOVAs for throughput scores ($r \cdot m^{-1}$) demonstrated significant mean differences for the Mathematical Processing task (MTH; $p < 0.001$, $\eta^2_p = 0.625$) where *post hoc* pairwise comparisons demonstrated that the post-fatigue throughput (32.0 ± 8.8 $r \cdot m^{-1}$) was significantly greater than the pre-fatigue (23.8 ± 7.4 $r \cdot m^{-1}$, $p = 0.003$, $d = 1.01$) and the familiarization throughput (26.4 ± 5.3 $r \cdot m^{-1}$, $p = 0.024$, $d = 0.77$). The Coded Substitution-Delay task also demonstrated significant mean differences (CDD; $p = 0.027$, $\eta^2_p = 0.394$) with *post hoc* pairwise comparisons demonstrating that the post-fatigue throughput (49.3 ± 14.4 $r \cdot m^{-1}$) was significantly less than the pre-fatigue throughput (63.2 ± 9.6 $r \cdot m^{-1}$, $p = 0.011$, $d = 1.14$). The repeated measures ANOVAs for reaction time (ms) demonstrated significant mean differences for MTH ($p < 0.001$, $\eta^2_p = 0.624$) where *post hoc* pairwise comparisons demonstrated that the post-fatigue reaction time (1885.2 ± 582.8 ms) was significantly less than the pre-fatigue (2518.2 ± 884.8 ms, $p = 0.005$, $d = 0.85$) and familiarization (2253.7 ± 567.6 ms, $p = 0.009$, $d = 0.64$) reaction times. The Go/No-Go task demonstrated significant mean differences (GNG; $p = 0.031$, $\eta^2_p = 0.320$) with *post hoc* pairwise comparisons demonstrating that the post-fatigue (285.9 ± 16.3 ms) was significantly less than the pre-fatigue (298.5 ± 12.1 ms, $p = 0.006$, $d = 0.88$) reaction times. High-intensity resistance exercise may elicit domain-specific influences on cognitive function, characterized by the facilitation of simple cognitive tasks and impairments of complex cognitive tasks.

Key words: Muscle fatigue, automated neuropsychological assessment metrics, back squat, exercise stress.

Introduction

In general, the physiological responses to acute exercise have been demonstrated to elicit significant changes in cognitive function (Tomporowski 2003; Lambourne and Tomporowski 2010; Chang et al. 2012; Browne et al. 2017). Theoretically, the influence of exercise on cognitive function has been thought to follow an inverted-U relationship, similar to the arousal theory originally described by Yerkes and Dodson (1908), who first theorized that as exercise intensity increases, the cognitive function would be facilitated until a critical intensity is surpassed at which point cognitive function will be impaired. We, therefore, hypothesized cognitive functions would be negatively affected. However, data had shown that acute bouts of moderate-intensity aerobic exercise had been demonstrated to elicit significant improvements on measures of cognitive function (Lambourne and Tomporowski 2010; Chang et al. 2012). However, studies examining the influence of high-intensity exercise had reported equivocal findings (Browne et al. 2017; Moreau and Chou 2019), demonstrating both faciliatory (Tsai et al. 2014; Chang et al. 2017) and inhibitory (Mekari et al. 2015; Smith et al. 2016) influences on cognitive function. But the type of high-intensity resistance exercise examined in this study, from our perspective, would appear to impair cognitive functions.

This hypothesis was based on the many influences that such high-intensity exercise stimulates that may mediate dysfunctional mechanisms in the brain related to cognition. It has been shown that high-intensity exercise causes dramatic changes in brain metabolism (Dietrich and Audiffren 2011; Mekari et al. 2015,) with elevated neurochemical concentrations (Izquierdo et al. 2009; Dietrich and Audiffren 2011; Tsai et al. 2014) that have been thought to mediate declines in cognitive function. We understood from our prior work that a significant physical stress was associated with the proposed high-intensity resistance exercise protocol (6 sets of 10 RM with 2 minutes rest between sets). A dramatic sympatho-adrenergic-cortical stress signaling responses have been demonstrated in addition to high levels of glycolytic metabolic stress (Kraemer and Ratamess 2005; French et al. 2007; Izquierdo et al. 2009). This further supported our *a priori* hypothesis that such stressors would overtly impair cognitive functions, even in trained men. Thus, the importance of this study was supported by the paucity of data examining such

Received: 07 March 2021 / Accepted: 22 April 2021 / Published (online): 03 May 2021

high-intensity exercise and the need for more context to understand prior work on high-intensity resistance exercise (Chang et al. 2012; Browne et al. 2017; French et al. 2007).

We had an established model for examining cognitive function due to our prior work with the Automated Neuropsychological Assessment Metrics (ANAM), a computer-based testing system developed by the United States Department of Defense to assess cognitive function (CSRC 2012). The ANAM has previously been demonstrated to be a sensitive and valid measure of cognitive impairments in young and athletic populations (Sours et al. 2015; Vincent et al. 2018a). Furthermore, the ANAM exhibits excellent test-retest reliability (Vincent et al. 2018b) and has been demonstrated to achieve stable test results following only two test administrations (Kaminski et al. 2009). Thus, we had a solid neurophysiological basis for our hypothesis, including prior results in the literature (Mekari et al. 2015; Smith et al. 2016; Browne et al. 2017) and an effective experimental tool would allow us to assess cognition consequent to high-intensity resistance exercise stress. Therefore, the purpose of the present study was to examine the influence of a high-intensity back squat protocol on cognitive functions.

Methods

Participants

Ten resistance-trained men (Mean ± SD: age = 24.4 ± 3.2 yrs; body mass = 85.7 ± 11.8 kg; height = 1.78 ± 0.08 m; 1 repetition maximum (1RM) = 139.0 ± 24.1 kg; 1 RM to body mass ratio: 1.64 ± 0.35) experienced in training with the barbell squat exercise volunteered to participate in this study. The participants were required to regularly participate in resistance training (≥ 3 times/week) for at least one year prior to the study. The participants were considered healthy and screened for any conditions that would confound the experimental findings, including neurological disorders, medications, drug use, musculoskeletal injuries, high blood pressure, concussions, epileptic or sleep disorders, tobacco use, or alcohol consumption >3 drinks/day or 18 drinks/wk. Additionally, each participant met with a registered dietitian and screened for a normal diet and was instructed how to abstain from caffeine consumption 24 hours before each test visit. The University's Institutional Review Board approved all experimental procedures. All participants signed an informed consent document prior to the initiation of the study after having the benefits and risks of the study explained to them.

Familiarization

Each participant was thoroughly familiarized with the experimental back squat testing protocols and the Automated Neuropsychological Assessment Metrics (ANAM). Each participant then completed a baseline ANAM during the familiarization phase. The ANAM core battery is a series of tests that were selected due to their sensitivity to subtle effects of a mild brain injury. The ANAM measures various cognitive domains, including response speed, attention and concentration, immediate and delayed memory, spatial processing, and decision processing speed and efficiency (CSRC 2012). The ANAM is considered a highly sensitive, precise, and objective measure of cognitive function appropriate for research in healthy individuals and patient populations (Bleiberg et al. 2000). The tasks comprising the ANAM Core test battery are described in Table 1.

Strength testing

Following the ANAM familiarization, participants were evaluated for their 1-repetition maximum (1RM) back squat using a free weight barbell (EliteFTS, London, OH) and methods previously described by Shimano et al. (Shimano et al. 2006). In brief, after a generalized dynamic warm-up, participants performed 5-10 repetitions at approximately 40-60% of their perceived maximum, followed by a second set of 3-5 repetitions at 60-80%, followed by one repetition attempts with progressively heavier load until a 1RM was established. To perform a squat, the participant descended to a parallel position by

Table 1. Descriptions of the ANAM Core test battery tasks in the order presented to participants.

Task	Description
Simple Reaction Time (SRT)	Measures visuomotor processing speed, simple motor speed and attention. A series of symbols was presented on display; the subject had to respond as quickly as possible by clicking on the mouse each time the symbol appeared.
Coded Substitution-Learning (CDS)	Measures visual scanning, visual perception, attention, associative learning, and information processing. The subject compared a displayed digit-symbol pair with a set of defined digit-symbol pairs (the key) presented at the top of the screen. The subject pressed on the designated mouse button to indicate whether the pair in question was correct or incorrect relative to the key.
Procedural Reaction Time (PRO)	Measures information processing speed, visuomotor reaction time, simple decision making, and attention. The subject was presented with a number (2-5); the subject pressed one designated button for a low number (2 or 3) or another designated button for a high number (4 or 5).
Mathematical Processing (MTH)	Assesses basic computational skills, concentration, and working memory. Arithmetic problems involving 3 single-digit numbers and 2 operators were displayed. The subject pressed buttons to indicate whether the answer to the problem is less than 5 or greater than 5.
Coded Substitution-Delay (CDD)	A measure of learning and delayed visual recognition memory. The subject was presented with a digit-symbol pair and must decide from memory if the pairing was correct based on the key presented during the Code Substitution (learning) test taken earlier.
Go/No-Go (GNG)	Measures response inhibition. The subject was presented with two characters, "x" and "o." The subject responded as quickly as possible to the "x" by pressing a button each time it appeared. When the "o" appeared, the user was to do nothing.
Simple Reaction Time 2 (SR2)	A repeat of the SRT task (see above).

flexing both knees and hips until the greater trochanter of the femur reached the horizontal plane of the superior border of the patella, after which they ascended to the upright standing position to complete the movement. After every set, the participants rated their perceived exertion using the CRQ-10 Rating of Perceived Exertion (RPE) scale with magnitude estimation, allowing the subject to give an RPE rating higher than 10 (Noble et al. 1983). Following the 1RM, the participants scheduled their test visit. They were asked to abstain from caffeine 24 hours and exercise 72 hours prior to the visit to reduce the likelihood of delayed onset muscle soreness or muscle damage that might impair performance for the test day. Additionally, the participants were instructed to arrive well hydrated on the morning of the visit with a suggestion of consuming ~1,000 mL of water the evening before.

Testing protocols

Following the familiarization visits, the participants were scheduled within seven days for the test visit. The participants reported to the laboratory where hydration status was assessed using a high precision TS400 Clinical Refractometer (Reichert Inc., Buffalo, NY) to assure all participants were considered euhydrated (urine specific gravity [USG $\leq$ 1.020]) for all testing. Based on this criterion, all participants in this study were hydrated before testing. Height and body mass measures were then obtained using a Seca 763 scale/stadiometer (Seca Inc., Chino, CA). Prior to the pre-fatigue ANAM administration, the participants sat for 10 minutes before having their blood lactate and heart rate measured as a baseline for resting values. Blood lactate concentrations were measured in duplicate from a single fingerpick using a Nova Biomedical Lactate Plus analyzer (Waltham, MA). Heart rate was obtained at rest and during the exercise protocol using a Polar Heart Rate Monitor (Lake Success, NY).

Back squat test visit

All test visits were scheduled prior to 11 am. The participants went through the same procedure leading up to the back squat protocol as in the 1RM testing protocol. Additionally, investigators verbally confirmed that the participants refrained from exercise 72 hours prior to the visit and refrained from consuming caffeine 24 hours prior to the visit. Following the pre-fatigue ANAM administration, the participants performed a generalized warm-up, then completed the test protocol of 6 sets of 10 repetitions with 2 minutes rest between sets of a barbell back squat loaded with 80% 1RM. Participants performed back squats in sequence to a parallel position established in the 1 RM test protocol. If a participant was unable to complete all 10 repetitions, the participant would drop the load onto the safety bars, and 4.5 kg would then be removed from the bar, and the participant continued onto the set until all 10 repetitions were performed. After each set, the participant rated their perceived exertion, and the investigators recorded their heart rate. Following sets 3 and 6, the investigators obtained a blood lactate measurement after heart rate and RPE were recorded. Investigators ensured the participant was using safe and proper form, changed weights if necessary, and recorded weights used, RPE, heart rate, and blood lactate. Immediately following the last blood lactate measurement, the participants completed a post-fatigue ANAM. After its completion, recovery heart rate, blood lactate, and USG were again recorded.

Statistical analyses

Performance for the ANAM protocol was assessed using reaction time (milliseconds; ms) and throughput when available, which was defined as the correct responses per minute($r \cdot m^{-1}$) and has previously been demonstrated to be a sensitive and stable measure of task performance (R. Thorne 2006; Vincent et al. 2018b). The results of each ANAM task were assessed using one-way repeated measures ANOVAs to determine mean differences in performance between the familiarization, pre-fatiguing, and post-fatiguing administrations. The time course of changes in load during the back squat protocol, heart rate, and blood lactate was examined using one-way repeated measures ANOVAs. Sphericity was assessed using Mauchly's test, and when violated, a Greenhouse-Geisser correction factor was applied. *Post hoc* pairwise comparisons with Bonferroni corrections were utilized when appropriate. Effects sizes for each repeated measures ANOVA (partial eta squared; η_p^2) and paired-samples *t*-test (Cohen's *d*) were calculated. Significance was defined as $p \leq 0.05$ and all statistical analyses were performed using SPSS Statistics Version 27 (IBM Corp., Armonk, NY).

Results

Back squat load, heart rate, and blood lactate

As expected with this exercise protocol, dramatic fatigue took place. By set 4, we observed a significant decrease in the percentage of 1RM as loading had to be reduced to perform the 10 repetitions. The repeated measures ANOVA for back squat load demonstrated significant mean differences ($p < 0.001$, η2p = 0.790) with post hoc pairwise comparisons demonstrating a significant decline in load compared to Set 1 (80.0 ± 0.0%) beginning at set 4 (72.6 ± 5.7%, d = 1.84; Table 1). The repeated measures ANOVA for heart rate ($p < 0.001$, η2p = 0.967) and blood lactate ($p < 0.001$, η2p = 0.900) exhibited mean differences across the back squat protocol that were significantly higher than resting values (Table 2).

ANAM Performance

The results of the repeated measures ANOVAs for the throughput scores for each ANAM protocol demonstrated significant mean differences for MTH ($p < 0.001$, η2p = 0.625), CCD (p = 0.027, η2p = 0.394), and SR2 ($p = 0.032$, η2p = 0.324) (Table 3). Post hoc pairwise comparisons for MTH demonstrated that the post-fatigue throughput (32.0 ± 8.8 $r \cdot m^{-1}$) was significantly greater than the pre-fatigue throughput (23.8 ± 7.4 $r \cdot m^{-1}$, $p = 0.003$, d =1.01) and the familiarization throughput (26.4 ± 5.3 r·m-1, p =0.024, d = 0.77). Post hoc pairwise comparisons for CDD demonstrated that the post-fatigue throughput (49.3 ± 14.4 $r \cdot m^{-1}$) was significantly less than the pre-fatigue throughput (63.2 ± 9.6 $r \cdot m^{-1}$, $p = 0.011$, d = 1.14). There were no significant ($p > 0.05$) post hoc pairwise comparisons for SR2 throughput.

The results of the repeated measures ANOVAs for the reaction times for each ANAM protocol demonstrated significant mean differences for MTH ($p < 0.001$, $\eta 2p = 0.624$), GNG, ($p = 0.031$, $\eta 2p = 0.320$), and SR2 ($p = 0.042$, $\eta 2p = 0.625$) (Table 4). Post hoc pairwise comparisons for MTH demonstrated that the post-fatigue reaction time (1885.2 ± 582.8 ms) was significantly lower than the familiarization reaction time (2253.7 ± 567.6 ms, $p = 0.009$, d = 0.64) and the pre-fatigue reaction time (2518.2 ± 884.8 ms, $p = 0.005$, d = 0.85). Post hoc pairwise comparisons for GNG demonstrated that the post-fatigue reaction time (285.9 ± 16.3 ms) was significantly lower than the pre-fatigue reaction time (298.5 ± 12.1 ms, $p = 0.006$, d = 0.88). Post hoc pairwise comparisons for SR2 demonstrated that the familiarization reaction time (235.5 ± 18.7 ms) was significantly lower than the pre-fatigue reaction time (252.0 ± 24.3, $p = 0.044$, d = 0.76).

Table 2. Mean ± SD of back squat load, heart rate, and blood lactate responses across the fatiguing task. Load significantly (P < 0.05) declined after Set 3 and heart and blood lactate were significantly elevated above rest at all time points.

	Resting	Set 1	Set2	Set 3	Set 4	Set 5	Set 6	Recovery
Load (% 1RM)		80.0 ± 0.0	78.0 ± 2.8	76.1 ± 3.6	72.7 ± 5.7	68.0 ± 7.1	62.8 ± 7.1	
Heart Rate (beats per minute)	65 ± 9	171 ± 10	174 ± 12	176 ± 6	174 ± 11	174 ± 10	179 ± 7	100 ± 12
Blood Lactate ($mmol \cdot L^{-1}$)	1.5 ± 0.6			13.8 ± 4.4			13.3 ± 2.1	6.6 ± 2.8

Table 3. Mean ± SD of throughput scores ($r \cdot m^{-1}$) for the ANAM protocol.

	Familiarization	Pre-Fatigue	Post-Fatigue	*p*-Value
SRT	257.2 ± 18.6	251.0 ± 23.1	260.8 ± 24.9	0.231
CDS	68.2 ± 9.6	65.6 ± 6.4	66.2 ± 6.2	0.274
PRO	113.7 ± 10.6	118.3 ± 12.0	116.5 ± 14.3	0.554
MTH	26.4 ± 5.3	23.8 ± 7.4	32.0 ± 8.8*	<0.001
CDD	65.8 ± 11.5	63.2 ± 9.6	49.3 ± 14.4*	0.027
GNG	-	-	-	-
SR2	256.1 ± 19.5#	240.0 ± 22.3	240.5 ± 21.1	0.032

SRT = Simple Reaction Time ; CDS = Coded Substitution-Learning; PRO = Procedural Reaction Time; MTH = Mathematical Processing; CDD = Coded Substitution-Delay; GNG = Go/No-Go; SR2 = Simple Reaction Time 2. *P*-values were determined from repeated measures ANOVAs, * Indicates significant ($p < 0.05$) difference from pre-fatigue values as determined from *post-hoc* pairwise comparison. # = ($p < 0.05$) from pre-fatigue and post-fatigue values.

Table 4. Mean ± SD reaction times (ms) for the ANAM protocol.

	Familiarization (ms)	Pre-Fatigue (ms)	Post-Fatigue (ms)	*p*-Value
SRT	234.4 ± 17.6	241.1 ± 24.0	232.0 ± 22.3	0.263
CDS	858.8 ± 146.7	590.6 ± 86.1	859.7 ± 89.9	0.406
PRO	510.9 ± 58.3	494.6 ± 61.1	500.6 ± 54.6	0.54
MTH	2253.7 ± 567.6	2518.2 ± 884.8	1885.2 ± 582.8*	<0.001
CDD	881.1 ± 113.8	937.9 ± 139.2	1104.4 ± 294.0	0.078
GNG	296.0 ± 15.9	298.5 ± 12.1	285.9 ± 16.3*	0.031
SR2	235.5 ± 18.7#	252.0 ± 24.3	251.3 ± 23.5	0.042

SRT = Simple Reaction Time ; CDS = Coded Substitution-Learning; PRO = Procedural Reaction Time; MTH = Mathematical Processing; CDD = Coded Substitution-Delay; GNG = Go/No-Go; SR2 = Simple Reaction Time 2. *P*-values were determined from repeated measures ANOVAs, * Indicates significant ($p < 0.05$) difference from pre-fatigue values as determined from *post-hoc* pairwise comparisons. # = ($p < 0.05$) from pre-fatigue and post-fatigue values.

Discussion

The primary purpose of this study was to examine changes in measures of cognitive function with a high-intensity resistance exercise protocol that has been used many times in prior studies to examine different physiological responses to exercise stress. We had hypothesized that overall impairments would be observed due to the significant physiological stressors. Our results showed that certain aspects of cognitive functions were enhanced, and thus, our hypothesis for overt negative effects on cognition functions with such exercise stress had to be rejected. Despite the elevated perceptual and physiological stressors, improvements in the MTH and GNG tasks of the ANAM were exhibited in both accuracy and reaction times (Tables 3 and 4, respectively). Our results did reflect some consistency with prior work (Tsai et al. 2014; Chang et al. 2017) that also reported improved performance in measures of reaction time and information processing following an acute bout of high-intensity resistance exercise (i.e., 2 sets of 10 repetitions for 6 exercises at 80% of 1RM) for the reaction time for a Go/No-Go test which was significantly improved and improved accuracy. Chang et al. (2017) also compared changes in cognitive function utilizing a computer-based Stroop test program 15 minutes following either high-intensity resistance exercise (HIR) consisting of 3 sets of 8-10 repetitions at 80% 1RM for 7 exercises which demonstrated significant improvements for increases in problems completed and significantly greater improvement in reaction times.

While few studies have examined the influence of a high-intensity resistance exercise modality on cognitive function (Chang et al. 2012; Browne et al. 2017), literature reviews examining the influence of high-intensity aerobic exercise (e.g., cycling and running) on cognitive function have a drawn equivocal conclusions. Moreau and Chou (2019) included 28 studies utilizing cycling, treadmill running, or body mass movements with an intensity criterion of 77-88.5% heart rate max or 59.5 to 79.9% of maximal power output. They reported acute improvements across numerous cognitive domains. Browne et al. (2017) examined 10 studies utilizing either cycling or running with an intensity criterion of equal to or greater than 80% of maximal power output and concluded that simple cognitive tasks were not affected by high-intensity exercise. Surprisingly to us, the improvements in the MTH and GNG tasks observed in this study following the back squat protocol indicated that high-intensity resistance training exercise might facilitate cognitive domains associated with basic computational skills and response inhibition.

However, part of our hypothesis of negative effects of high-intensity exercise did prove true. In part, we demonstrated that the CDD task of the ANAM with a reduction in throughput scores but not in reaction time, which suggested a reduction in the accuracy of performance but not a change in the speed of responsiveness to the task. The CDD task involves the delayed recall of symbol-numeral pairings approximately 7-8 minutes following CDS task when the participants were first taught the symbol-numeral pairings (CSRC 2012). It should be noted that the CDS is described as a measure of processing speed: since the purpose of the task is to teach the participants the correct symbol-number pairings, the majority of the symbol-number pairings presenting during this task were correct (CSRC 2012). The present study results demonstrated no significant changes in the CDS test, which suggested that the reduction in the CDD performance was likely not related to learning the number-symbol pairings but rather the correct recollection of the correct number-symbol pairings. Previous studies have also demonstrated a decline in cognitive performance following high-intensity exercise (Wang et al. 2013; Mekari et al. 2015; Smith et al. 2016). For example, Mekari et al. (2015) examined information processing and executive function utilizing a modified Stroop test during low- (40% of peak power output), moderate- (60%), and high-intensity (85%) cycling. They demonstrated a significant increase in reaction time (i.e., slower performance) and a significant reduction in accuracy in the high-intensity exercise group when compared to the low-intensity group. Wang et al. (2013) reported significant declines in measures of executive function as determined by the Wisconsin Card Sorting Test during cycling at 80% of HRR when compared to cycling at 30% HRR, 50% HRR, and at rest. Additionally, Smith et al. (2016) demonstrated significantly slower reaction times and significantly greater omission and decision error rates on a Go/No-Go test during treadmill running at high intensity (80% HRR) when compared to moderate (70% HRR) and resting conditions. Our study adds to this understanding showing significant declines in this aspect of cognitive function following high-intensity resistance exercise.

Data from our study showed a mosaic response pattern in cognitive functions consequent to high-intensity resistance exercise. Meaning there was an impaired performance in a cognitive domain associated with memory and recall but an improved performance in cognitive domains associated with basic computational skills. This response inhibition exhibited indicates that high-intensity resistance exercise may elicit unique differential responses in various cognitive domains. Browne et al. (2017) provided a simplified characterization of the various cognitive domains: they suggested that tests assessing reaction time and information processing represent a general, simple cognitive domain; tests assessing executive function, attention, and memory represent a complex cognitive domain. A growing body of evidence suggests that exercise-induced changes in cognitive function may be domain-specific (Audiffren et al. 2008, 2009; Browne et al. 2017; Chang et al. 2017). For example, Audiffren et al. (2008, 2009) examined the influence of cycle ergometry at 90% of the ventilatory threshold for 35 minutes on measures of simple and complex cognitive tasks. In the first study, Audiffren et al. (2008) utilized a simple two-choice auditory test and reported significant improvements in reaction time during the exercise protocol. In the subsequent study, however, Audiffren et al. (2009) utilized a random number generation test to assess executive function and reported that compared to rest, the participants exhibited a change in their random number generation strategy to a "less effortful strategy of random number generation."

Additionally, Chang et al. (2017) utilized a modified Stroop test that consisted of a neutral task assessing simple reaction time and an incongruent task assessing executive function (response inhibition). They reported significant improvements in reaction time compared to the resting condition during the neural task, but no differences in the reaction time for the incongruent task following 3 sets of 8-10 repetitions at 80% 1RM for 7 resistance training exercises. Thus, the improvements in simple cognitive tasks, particularly reaction time and information processing, with the concomitant impairment of a complex cognitive task, in particular memory and recall, exhibited in the present study suggested that high-intensity resistance training may elicit domain-specific differences in cognitive performance.

The mechanisms underlying the exercise-induced changes in cognitive function have yet to be fully elucidated. However, previous studies have utilized metabolic (Dietrich and Audiffren 2011) and neurochemical (McMorris et al. 2016) hypotheses to describe the exercise-cognition interaction. Specifically, the transient hypofrontality hypothesis suggested that in the context of exercise, as exercise intensity increases, metabolic resources are allocated from areas of the brain less critical in maintaining the physical demands of the exercise, such as the prefrontal cortex, to areas of the brain associated with maintaining the physical demands, such as the motor cortices (Dietrich and Audiffren 2011). This theoretically results in the facilitation of sensory and motor tasks, while potentially impairing executive function (Dietrich and Audiffren 2011; Moreau and Chou 2019). The neuroendocrine hypothesis suggests that the exercise-induced changes in the neurochemicals within the brain, such as catecholamines, cortisol, and serotonin, affect cognitive function characterized as an inverted-U relationship (McMorris et al. 2016; Moreau and Chou 2019). As exercise intensity increases, these neurochemicals function to facilitate cognitive function. However, at higher intensities, the excessive concentrations of these chemicals may inhibit cognitive function (McMorris et al. 2016; Moreau and Chou 2019). The methodologies in the present study were unable to substantiate either of these hypotheses as neither brain metabolism, nor endocrine responses were assessed. The efficacy in eliciting exercise-induced changes in various cognitive domains suggested that the high-intensity back squat protocol is an effective paradigm. It might be utilized in future studies to examine these hypotheses and the relationships between acute, high-intensity resistance exercise and cognitive functions along with neurological/endocrine signaling.

Conclusion

In conclusion, the present study results demonstrated that an acute bout of high-intensity resistance exercise elicited domain-specific changes in cognitive function. Tasks associated with information processing and response inhibition exhibited improvements, while tasks associated with memory and recall exhibited decrements following the high-intensity resistance exercise stress.

Acknowledgements
The authors have no conflict of interests to declare. The present study was in compliance with all current laws of the United States of America and was approved by the Institutional Review Board for use of human subjects at The Ohio State University, Columbus, Ohio, USA. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the first author who was team leaders for the study. Dr. Kraemer was the principal investigator and corresponding author for the study.

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Key points

- High-intensity squat resistance exercise may elicit domain-specific influences on cognitive function.
- Tasks associated with information processing and response inhibition was exhibited improvement for simple cognitive tasks.
- Complex cognitive associated with memory and recall exhibited decrements and impairments following the high-intensity back squat protocol.
- Understanding changes in cognition under extreme physical stress is important for interpretation of physiological influences.

AUTHOR BIOGRAPHY

John Paul V. ANDERS
Employment
University of Nebraska-Lincoln, USA
Degree
MA
Research interests
Exercise-Induce fatigue, neuromuscular function, cognition, and sports nutrition.
E-mail: janders@huskers.unl.edu

William J. KRAEMER
Employment
The Ohio State University, USA
Degree
Ph.D.
Research interests
Resistance training physiology
E-mail: drwilliamkraemer@gmail.com

Robert U. NEWTON
Employment
Edith Cowan University, AUSTRALIA
Degree
Ph.D.
Research interests
Exercise medicine, rehabilitative cancer therapy, exercise medicine on tumor biology, and strength, body composition, and functional ability in cancer patients.
E-mail:

Emily M. POST
Employment
Ohio Dominican University, USA
Degree
Ph.D.
Research interests
Exercise physiology, human anatomy, and bioenergetics.

Lydia K. CALDWELL
Employment
University of North Texas, USA
Degree
Ph.D.
Research interests
Performance and recovery optimization, physiological monitoring, neuroendocrine stress, and augments recovery strategies

Matthew K. BEELER
Employment
Hastings College, USA
Degree
Ph.D.
Research interests
Resistance training, periodization, and optimizing performance.

Emily R. MARTINI
Employment
The Ohio State University, USA
Degree
MS
Research interests
Exercise physiology, cardiovascular physiology, apparel technology and sports performance

Jeff S. VOLEK
Employment
The Ohio State University, USA
Degree
Ph.D., RD
Research interests
Ketogenic diet, ketone physiology, dietetics and nutrition, exercise nutrition

Keijo HÄKKINEN
Employment
University of Jyväskylä, FINLAND
Degree
Ph.D.
Research interests
biomechanics, muscle function, neuromuscular physiology, and athletic performance

Carl M. MARESH
Employment
The Ohio State University
Degree
Ph.D.
Research interests
Physiological responses to environmental stressors, hydration and performance, performance adaptations to extreme environments

Scott M. HAYES
Employment
The Ohio State University
Degree
Ph.D.
Research interests
The relationship between physical activity, fitness, cognition and the brain, neural correlates of cognition, application of MRI techniques to clinical populations with memory impairments

✉ **William J. Kraemer, Ph.D.**
Professor , Department of Human Sciences, 305 Annie & John Glenn Ave Office A054 PAES Bldg., The Ohio State University, Columbus, OH 43210, USA