Psychology of Sport and Exercise 22 (2016) 286–293

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

journal homepage: www.elsevier.com/locate/psychsport

The effects of acute resistance exercise on young and older males' working memory☆

Shu-Shih Hsieh [a], Yu-Kai Chang [b], Tsung-Min Hung [a,*], Chin-Lung Fang [a,**]

[a] Department of Physical Education, National Taiwan Normal University, Taipei, Taiwan
[b] Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan, Taiwan

ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form
21 August 2015
Accepted 8 September 2015
Available online 10 September 2015

Keywords:
Acute exercise
Sternberg paradigm
Cognitive performance
Selective effect

ABSTRACT

Objectives: The aim of the current study was two-fold: to examine the effects of acute, moderate intensity resistance exercise (RE) on working memory in young and older males, respectively.
Design: A two-study approach with a within-subjects design.
Methods: Study 1 recruited 20 young males aged 21–30 years. Participants underwent two experimental sessions, the exercise session and reading session, in a counterbalanced order. The RE protocol included two sets of 10 repetitions at 70% of 10-repetition maximum of eight muscle exercises. The Sternberg working memory paradigm with two probe types (in-set probes and out-of-set probes) was used as the cognitive task where reaction times (RT) and response accuracy were identified. Study 2 recruited 20 older male adults aged 65–72 years. The methods and experimental procedures were the same as Study 1.
Results: In Study 1, young males demonstrated shorter RTs after the exercise treatment as compared with the reading treatment for both probe types. In Study 2, older males showed shorter RTs after the exercise treatment as compared with the reading treatment in the out-of-set probes only.
Conclusions: While acute RE benefited working memory in both young and older males, rather than general facilitation, it was shown to have a disproportionately larger effect on older males for tasks involving higher working memory demands.

1. Introduction

Executive function is a top-down process comprised of multiple mental processes that are involved in goal-directed behaviors (Etnier & Chang, 2009; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Core subcomponents of executive function include inhibitory control, working memory, and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). Working memory, in particular, is a limited-capacity and multicomponent cognitive ability to retain and manipulate complex information within a short period of time (Baddeley, 2003). Studies have indicated that working memory is critical for different mental processes such as attentional allocation (Chun, Golomb, & Turk-Browne, 2011), semantic processing (Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2014), and switching between mental sets (Kray & Lindenberger, 2000). In addition, working memory (e.g., updating information, translating instructions into actions) is essential for making sense of things that unfold over time (i.e., remembering what happened earlier and relating it to what comes later) (Diamond, 2013). Thus, any approach that can enhance working memory is particularly relevant.

A single bout of exercise can be regarded as a physiological stimulus which, under certain circumstances, can enhance cognitive performance. The cognitive-energetic model in cognitive psychology postulates an inverted-U shape relationship between acute exercise and cognitive performance such that low-intensity exercise (low arousal) may induce poor cognitive performance, moderate-intensity exercise (optimal arousal) may result in maximal cognitive performance, and vigorous exercise (high arousal) may impair cognitive performance (Audiffren, 2009). The

☆ The research was partially supported by a grant from the Ministry of Science and Technology in Taiwan (NSC 102-2410-H-003-139) to Chin-Lung Fang.
* Corresponding author. Department of Physical Education, National Taiwan Normal University, No.162, Sec. 1, Heping E. Rd., Da'an Dist., Taipei City 10610, Taiwan.
** Corresponding author. Department of Physical Education, National Taiwan Normal University, No.162, Sec. 1, Heping E. Rd., Da'an Dist., Taipei City 10610, Taiwan.
E-mail addresses: ernesthungkimo@yahoo.com.tw (T.-M. Hung), frankfang333@gmail.com (C.-L. Fang).

http://dx.doi.org/10.1016/j.psychsport.2015.09.004
1469-0292/

meta-regression analysis of Lambourne and Tomporowski (2010) also indicates that increased arousal can likely facilitate cognitive performance via improved memory storage and retrieval following exercise.

It has been reported that acute, moderate intensity aerobic exercise (AE) has a positive impact on working memory in samples of varying ages. For example, Pontifex, Hillman, Fernhall, Thompson, and Valentini (2009) showed that acute bouts of moderate-intensity (60–70% VO_{2max}) AE facilitated young adults' processing speeds in working memory as assessed by the Sternberg paradigm without a loss in response accuracy. In addition, the study of Hogan, Mata, and Carstensen (2013) revealed that moderate-intensity (50% $HR_{reserve}$) AE facilitated processing speeds in working memory as measured by the *n*-back task in young, middle-aged, and elderly adults without a speed-accuracy strategy. Collectively, these results have provided converging evidence to support the facilitative effect of acute, moderate intensity AE on working memory in different populations.

On the other hand, the effects of acute resistance exercise (RE) on different aspects of executive function have recently drawn attention from researchers because RE training is now considered as a critical component of exercise interventions, and it may provide multiple health benefits (e.g., muscle strength and endurance, functional capacity and independence, and cardiovascular health), including cognitive function, to both clinical and non-clinical populations (Chang, Pan, Chen, Tsai, & Huang, 2012; Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012; Williams et al., 2007). Following the premise of the cognitive-energetic model, the serial studies by Chang and colleagues (Chang, Chu, Chen, & Wang, 2011; Chang & Etnier, 2009; Chang, Ku, Tomporowski, Chen, & Huang, 2012; Chang, Tsai, Huang, Wang, & Chu, 2014) provide clear insight into the relationship between acute RE and executive function, and suggest that RE may improve inhibitory control in young and middle-aged adults (Chang & Etnier, 2009; Chang, Tsai, et al., 2014), and goal-planning in middle-aged adults (Chang et al., 2011; Chang, Ku, et al., 2012).

Despite the finding of beneficial effects of acute RE on the inhibitory control and goal-planning aspects of executive function, research on the relationship between acute RE and working memory is somewhat limited. To our knowledge, the only published work that has tested the effect of acute RE on working memory was Pontifex et al. (2009). However, the study found that acute RE was not beneficial to working memory as measured by the Sternberg task in young adults. These findings may be attributable to several methodological constraints (e.g., inappropriate RE intensity manipulation, variation in timing of administration of the cognitive task following exercise); thus, further clarification is warranted. First, the way that exercise intensity was manipulated needs to be considered. Previous studies on acute RE and executive function suggested an inverted U-shape relationship between exercise intensity and executive function (Chang et al., 2011; Chang & Etnier, 2009) such that RE with moderate intensity may facilitate executive function to a greater extent than RE of a higher or lower intensity. Specifically, Chang and Etnier (2009) and Chang et al. (2011) indicated that RE intensity prescribed at 70% 10-repetition maximum (10-RM) may induce better performance in executive function in young and middle-aged adults as compared with intensity prescribed at 100% 10-RM (relative to 75% 1-RM; Baechle & Earle, 2008). In Pontifex et al. (2009), the RE intensity was 80% 1-RM, which was actually even higher than the high intensity level in Chang and Etnier (2009) and Chang et al. (2011). Based on the inverted U-shape hypothesis, it may be speculated that the RE intensity manipulated by Pontifex et al. (2009) was too strenuous to benefit working memory performance. Second, the specific timing of the cognitive task administered after exercise cessation may also contribute to the non-significant results of Pontifex et al. (2009). The meta-analytical study of Chang, Labban, Gapin, and Etnier (2012) suggested that the timing of administration of the cognitive task following exercise cessation may significantly influence the effect of acute exercise, with tasks completed within 10 min of exercise cessation resulting in negative effects and tasks performed after 11–20 min of delay displaying positive effects. Participants in the study of Pontifex et al. (2009) performed the Sternberg task immediately following exercise cessation, which may have accordingly resulted in the non-significant outcomes.

Taken together, this current study was conducted in order to investigate the effects of acute RE on working memory after several methodological modifications. To our knowledge, the current study is the first to examine the effects of acute, moderate intensity RE on working memory. We hypothesized that working memory performance can be facilitated by acute bouts of moderate intensity RE. The present study was expected to extend the knowledge base regarding the relationship between acute exercise and working memory.

2. Study 1

2.1. Overview

Study 1 aimed to test the effects of acute, moderate intensity RE on young adults' working memory using a within-subjects design. Healthy and active male adults aged 21–30 years were recruited, and the Sternberg task was applied as the neuropsychological measure.

3. Method

3.1. Participants

Twenty healthy young men (23.95 ± 2.21 years) with at least 12 years of education and a score greater than 26 on the Mini Mental State Examination (MMSE) were recruited via advertisements distributed around Taipei City, Taiwan. Male participants were recruited because it has been suggested that gender differences exist in endocrine responses to RE in young adults (Kraemer et al., 1998) and, as a result, may affect any related cognitive changes (Rubia, Hyde, Halari, Giampietro, & Smith, 2010). This recruiting strategy helped us rule out the potential contaminating effect of gender on the behavioral results. Participants were also required to complete the Physical Activity Readiness Questionnaire (PARQ) to ensure the safety of their participation in the experiments. All participants were right-handed as determined by an oral report of handedness and had no cardiovascular diseases or neurological disorders. Participants had no experience in performing RE in the last few years prior participation in the current study, but most of them were regular exercisers. Written informed consent was obtained from all participants via a form approved by the Institutional Review Board of National Taiwan University.

3.2. Demographics

Age, education, and socioeconomic status were assessed by self-report. Height, weight, body mass index (BMI), and blood pressure were measured in the laboratory. Participation in physical activities was assessed using the Taiwanese version (Liou, Jwo, Yao, Chiang, & Huang, 2008) of the International Physical Activity Questionnaire (IPAQ), an international surveillance questionnaire used to assess the amount of weekly physical activity by metabolic equivalents (METs) (Bauman et al., 2009).

3.3. Exercise intensity manipulation check

Heart rate (HR) and rating of perceived exertion (RPE), the two commonly used indicators for exercise intensity in acute RE-cognition studies (Chang, Tsai, et al., 2014; Chang et al., 2011; Chang & Etnier, 2009; Chang, Ku, et al., 2012), were employed to check RE intensity in the present study. These indicators are commonly used because they are noninvasive, easy-to-measure, and able to provide valuable information on whether the exercise intensity manipulation is effective.

3.3.1. Heart rate

HRs were monitored using a tonometer (ORMEN HEM-7200). Four stages were recorded: pre-test HR (HR assessed immediately before conducting the cognitive pre-test), treatment HR (the average HR assessed during the exercise or reading rest period), post-treatment HR (HR assessed immediately after exercise or reading within a 3-min time frame), and post-test HR (HR assessed immediately before conducting the cognitive post-test). The treatment HR of the RE refers to the average of the eight HR measures collected after each of the eight exercises, whereas the treatment HR of the reading rest refers to the average HR assessed every 3 min during that phase.

3.3.2. Rating of perceived exertion

The RPE scale ranged from 6 to 20 and was used to provide a subjective rating of individuals' perceptions of their efforts during exercise (Borg, 1982). RPEs were recorded after each of the eight exercises during the exercise phase.

3.4. Working memory task

The cognitive task was administered in a quiet, sound-attenuated room. The study used a modified Sternberg paradigm (Sternberg, 1966) to assess working memory. This paradigm is well-suited to exercise-cognition research (Chang, Huang, Chen, & Hung, 2013; Kamijo et al., 2011; Pontifex et al., 2009) and was administered via NeuroScan STIM software (2.0 version; Neuro Inc., EI Paso, TX, USA). The visual stimulus (e.g., 647, 789, 927, and 621) was presented in white against a black background and had a size of 3 × 3 cm. The task trial started with a fixation cross that was displayed in the middle of the monitor for 500 ms. Then, a stimulus string of three numbers (e.g., 647) was presented for 200 ms followed by a 3000-ms delay. A single probe number was then presented for 500 ms. An in-set probe was a single probe number randomly chosen as one of the previous three numbers shown (e.g., 7), whereas an out-of-set probe was a number that was not one of the three numbers shown (e.g., 5). Participants were instructed to respond as quickly and accurately as possible within the 1000 ms response window by pressing a button with either their right or left index finger for an in-set probe or an out-of-set probe, respectively. In general, responses to out-of-set probes should be longer compared to in-set probes because the out-of-set probes may require more time for stimulus evaluation and identification (Pelosi, Hayward, & Blumhardt, 1995, 1998).

Practice trials were given to each participant first. The formal test was started when the participant could perform the task properly, namely, they could respond to the stimulus as fast as possible and reach an accuracy criterion of 75% over 20 practice trials (Chang et al., 2013). A total of 160 in-set and out-of-set probes were divided into four blocks of 40 trials, and each probe had an equal probability of being presented. One-minute rest intervals were presented between each block. The total duration of the experiment was approximately 15 min. Each performance was measured according to the RT and the accuracy of the participants' responses to each probe type (in-set and out-of-set probes).

3.5. Experimental procedures

Each participant was asked to visit the laboratory for three testing sessions, with at least 48 h between each visit. The first session consisted of baseline assessments and 10-RM testing. The participant was presented with a brief introduction to the experiment, completed an informed consent and then completed the PARQ, demographic, MMSE, and IPAQ questionnaires. After completing the questionnaires, participants were instructed to sit quietly in a dimly lit room for 15 min. At the end of the 15-min period, resting HR and blood pressure were assessed. Then, participants' 10-RMs for each of eight exercises were determined based on a testing protocol developed by Baechle and Earle (2008). 10-RM is the maximum weight one can lift in 10 repetitions for a given exercise. The eight exercises included chest presses, leg extensions, high pull-downs, leg curls, rowing, leg presses, shoulder presses, and biceps curls.

The second and third sessions consisted of five phases each: sitting rest, cognitive pre-test, treatment, post-treatment rest, and cognitive post-test. In session two, the participant was first required to sit quietly in a dimly lit room for 15 min. Then, the participant was given practice trials of the Sternberg task and performed four test blocks as a cognitive pre-test. Next, when assigned to the exercise treatment, the participant performed a 30-min RE protocol that included a 5–10-min warm-up and two sets of 10 repetitions at 70% of 10-RM of each of the eight exercises. The rest intervals between sets and exercises were 30 and 90 s, respectively. The protocol was based on previous studies (Chang, Tsai, et al., 2014) that revealed beneficial effects of acute RE with such intensity (i.e., 70% 10-RM) on cognitive performance in healthy adults. When assigned to the control treatment, the participant was instructed to sit quietly and read materials related to physical activity and mental health for 30 min. Then, the participant had another 10-min sitting rest period and then completed the same Sternberg task again as the cognitive post-test. Sessions two and three were counterbalanced to minimize potential order and practice effects. Fig. 1 presents the time course and experimental procedures for the second and third sessions.

3.6. Statistical analysis

All values are expressed as the mean ± SD. All of the data were processed using SPSS software (version 19.0 for Windows). To test the exercise intensity manipulation, a 2 (treatment: exercise, control) × 4 (time: pre-test, treatment, post-treatment, post-test) repeated measures (RM) ANOVA was computed for the HR data. Next, a 2 (treatment: exercise, control) × 2 (condition: in-set probe, out-of-set probe) × 2 (time: pre-test, post-test) RM ANOVA was applied for the RT and response accuracy data to test the effect of RE on performance in different task conditions. The *LSD* method was adopted for the post hoc analysis. The *Bonferroni* post hoc test was also adopted when levels of independent factors were three or above (e.g., the factor "Time" in the exercise intensity manipulation check analysis). The effect sizes (i.e., partial η^2s) were reported to complement the use of significance testing. An alpha of 0.05 was used as the level of statistical significance for all analyses.

4. Results

4.1. Demographics

Table 1 summarizes the demographics of the participants.

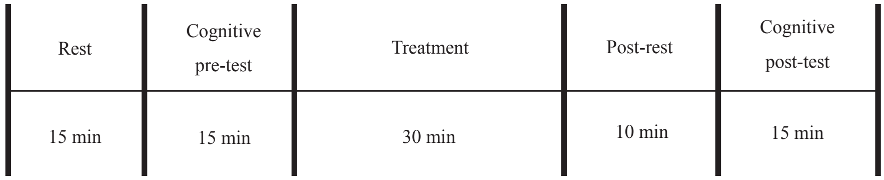

Fig. 1. The time course and procedure of experimental process.

4.2. Exercise intensity manipulation check

The 2 × 4 RM ANOVA indicated main effects of Treatment ($F(1, 19) = 104.73$, $p < .001$, partial $\eta^2 = 0.85$) and Time ($F(3, 17) = 67.37$, $p < .001$, partial $\eta^2 = 0.78$), and the interaction of Treatment by Time ($F(3, 17) = 85.37$, $p < .001$, partial $\eta^2 = 0.82$). A follow-up post hoc analysis revealed that in the exercise treatment, the treatment HR, post-treatment HR and post-test HR were significantly higher than the pre-test HR. The treatment HR and post-treatment HR were higher than the post-test HR. As for the control treatment, the treatment HR was significantly higher than the post-test HR.

As for RPE during the RE phase, results indicated an average of 13.38 ± 1.37, which was equivalent to an effort that is perceived as somewhat hard on the Borg scale. The aforementioned results suggested that the exercise intensity manipulation to induce physiological responses and increase arousal was effective. Table 2 illustrates HR fluctuations at different time points and RPE value during exercise.

4.3. Behavioral data

For RT performance, three-way RM ANOVA revealed a main effect of Condition ($F(1, 19) = 41.16$, $p < .001$, partial $\eta^2 = 0.69$), where the overall RTs of the out-of-set probes were significantly longer than that of the in-set probes. The main effect of Time ($F(1, 19) = 27.95$, $p < .001$, partial $\eta^2 = 0.60$) and the interaction of Treatment by Time ($F(1, 19) = 21.59$, $p < .001$, partial $\eta^2 = 0.53$) were also significant. A follow-up post hoc analysis indicated that post-test RTs in the exercise treatment (462.75 ± 86.17 ms) were significantly shorter than those in the control treatment (486.90 ± 76.48 ms) irrespective of condition, whereas no difference in the pre-test RTs between the exercise (503.68 ± 82.64 ms) and the control treatments (491.78 ± 72.61 ms) was observed. In the exercise treatment, post-test RTs were significantly shorter than the pre-test RTs irrespective of condition, while no difference between the pre-test RTs and post-test RTs in the control treatment was found.

The three-way RM ANOVA did not reveal any interactions or main effects for the response accuracy data. Table 3 presents the RT performance across conditions and stages.

Table 1
Demographics and 10-RM measures for young and older males.

Measure	Young	Older
	M (SD)	*M (SD)*
Sample size (N)	20	20
Age (years)	24.0 (2.2)	67.2 (1.8)
Height (cm)	175.2 (4.5)	166.6 (4.6)
Weight (kg)	72.1 (12.2)	64.1 (7.8)
BMI (kg/m^2)	23.4 (3.1)	23.0 (2.5)
MMSE (points)	29.8 (0.4)	29.5 (0.7)
Education (years)	16.4 (1.6)	16.3 (1.5)
Socioeconomic status	3.6 (1.3)	4.0 (1.2)
Resting HR (bpm)	68.9 (10.6)	65.9 (6.5)
Resting SBP (mmHg)	122.0 (10.2)	124.1 (10.4)
Resting DBP (mmHg)	70.2 (6.4)	72.4 (6.9)
IPAQ (METs)	1740.2 (905.9)	1984.6 (1267.2)
Chest press (kg)	64.1 (17.0)	36.0 (11.4)
Leg extension (kg)	39.1 (11.4)	22.8 (6.1)
Pull-down (kg)	66.0 (12.3)	50.7 (10.0)
Leg curl (kg)	21.5 (6.3)	7.4 (3.1)
Rowing (kg)	52.2 (15.3)	34.8 (8.4)
Leg press (kg)	215.1 (69.7)	90.2 (43.8)
Shoulder press (kg)	44.0 (19.3)	18.2 (8.0)
Biceps curl (kg)	33.6 (7.7)	26.9 (5.2)

Note. BMI: body mass index; MMSE: Mini Mental State Examination; HR: heart rate; bmp: beats per minute; SBP: systolic blood pressure; DBP: diastolic blood pressure; IPAQ: International Physical Activity Questionnaire; METs: metabolic equivalents.

Table 2
HR fluctuations at different time points and RPE values in young and older males.

	Young		Older	
	Exercise	Reading	Exercise	Reading
Pre-test (bpm)	68.1 ± 11.3	68.5 ± 9.3	67.3 ± 8.0	64.7 ± 6.7
Treatment (bpm)	94.2 ± 14.8	69.1 ± 7.6	82.1 ± 9.3	63.5 ± 6.5
Post-treatment (bpm)	93.1 ± 11.9	68.3 ± 7.1	79.4 ± 11.3	63.2 ± 6.8
Post-test (bpm)	83.3 ± 13.1	66.2 ± 8.7	74.6 ± 8.5	61.3 ± 6.0
RPE	13.4 ± 1.4	–	12.8 ± 1.0	–

Note. Data are presented as mean ± SD. bpm: beats per minute.

5. Discussion

The main finding in Study 1 was that acute RE facilitated young males' working memory as assessed 10 min following exercise. Specifically, moderate intensity RE facilitated young males' processing speeds in working memory tasks with lower- and higher mental loadings. Notably, working memory declines substantially in the elderly (Finnigan, O'Connell, Cummins, Broughton, & Robertson, 2011; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Park et al., 2002; Tays, Dywan, Capuana, & Segalowitz, 2011), resulting in negative impacts on everyday functioning and individual independence (Schmitter-Edgecombe & Parsey, 2014; Tucker-Drob, 2011). Since the positive impact of acute AE on older adults' working memory has been previously demonstrated (Hogan et al., 2013), the effects of acute RE on older adults' working memory should also be examined. Therefore, Study 2 was conducted in attempts to further previous findings.

6. Study 2

6.1. Overview

The purpose of Study 2 was to test the effects of acute, moderate intensity RE on working memory in older men with a within-subjects design. Healthy and active male adults aged 65–72 years were recruited, and the Sternberg paradigm was applied as neuropsychological measure. All experimental procedures were the same as Study 1.

7. Method

7.1. Participants

Twenty healthy older men (67.15 ± 1.81 years) with at least 12

Table 3
RT performances in the Sternberg task of young and older males.

		In-set		Out-of-set	
		Pre-test (ms)	Post-test (ms)	Pre-test (ms)	Post-test (ms)
Young	Exercise	477.7 ± 87.0	440.6 ± 94.3*#	529.7 ± 78.3	484.9 ± 79.9*#
	Reading	470.3 ± 83.7	463.0 ± 83.3	513.3 ± 66.9	510.8 ± 73.0
Old	Exercise	607.2 ± 83.8	562.4 ± 68.2*	671.4 ± 83.5	631.7 ± 69.5*
	Reading	604.7 ± 86.6	571.9 ± 72.5*	655.2 ± 89.0	647.1 ± 84.7

Note. Data are presented as the mean ± SD. * Significant difference between post-test and pre-test, $p \leq .05$. # Significant difference between treatment, $p \leq .05$.

years of education and a score of more than 26 on the MMSE were recruited via advertisements distributed around Taipei City, Taiwan. Similar to Study 1, Study 2 recruited only older males because it has been suggested that gender can affect cognitive performance in older populations due to transient changes in hormonal environments that occur in elderly women (Hogervorst, 2013). As with Study 1, participants were required to complete the PARQ to ensure the safety of their participation in the experiments. All participants were right-handed as determined by an oral report of handedness and had no cardiovascular diseases or neurological disorders. Participants had no experience in performing RE in the last few years prior participation in the current study, but most of them were regular exercisers. Written informed consent was obtained from all participants via a form approved by the Institutional Review Board of National Taiwan University.

7.2. Demographics, exercise intensity manipulation check, working memory task, experimental procedures, and statistical analyses

The descriptions of demographics, exercise intensity manipulation check, working memory task, experimental procedures, and statistical analyses were the same as that of Study 1.

8. Results

8.1. Demographics

Table 1 summarizes the demographics of participants.

8.2. Exercise intensity manipulation check

The 2 × 4 RM ANOVA revealed the main effects of Treatment ($F(1, 19) = 85.32$, $p < .001$, partial $\eta^2 = 0.82$), and Time ($F(3, 17) = 53.12$, $p < .001$, partial $\eta^2 = 0.90$), and the interaction of Treatment by Time ($F(3, 17) = 43.52$, $p < .001$, partial $\eta^2 = 0.89$). A follow-up post hoc analysis indicated that in the exercise treatment, the treatment HR, post-treatment HR and post-test HR were significantly higher than the pre-test HR. The treatment HR was higher than the post-treatment HR and post-test HR. The post-treatment HR was higher than the post-test HR. As for the control treatment, the pre-test and treatment HRs were significantly higher than the post-test HR.

The RPE results during the RE revealed an average of 12.84 ± 0.97, which was equivalent to an effort that is perceived as somewhat hard on the Borg scale. The results suggested that the exercise intensity manipulation for inducing physiological responses and increasing arousal was effective. Table 2 presents the HR fluctuations at different time points and RPE value during exercise.

8.3. Behavioral data

For RTs, three-way RM ANOVA revealed the main effects of Condition ($F(1, 19) = 48.17$, $p < .001$, partial $\eta^2 = 0.72$), with the overall RTs in the out-of-set probes found to be significantly longer compared to the in-set probes, and Time ($F(1, 19) = 34.22$, $p < .001$, partial $\eta^2 = 0.65$), with overall RTs in the pre-test stage that were significantly longer than in the post-test stage and were further superseded by a Treatment by Condition by Time interaction ($F(1, 19) = 5.30$, $p = .033$, partial $\eta^2 = 0.22$). A follow-up post hoc analysis indicated that for out-of-set probes, the post-test RT (631.70 ± 69.53 ms) was significantly shorter than the pre-test RT (671.40 ± 83.51) under the exercise treatment but not the control treatment. For in-set probes, significantly faster RTs were demonstrated by older males in the post-test stage compared to the pre-test stage under exercise (pre-test: 607.17 ± 83.79 ms; post-test: 562.38 ± 68.18 ms) and reading treatments (pre-test: 604.71 ± 86.58 ms; post-test: 571.91 ± 72.45 ms).

For the response accuracy, the three-way RM ANOVA did not reveal main effects or interaction effects. Table 3 presents the RT performance of the participants.

9. Discussion

The main finding in Study 2 was that acute RE benefited older males' working memory as assessed 10 min following exercise. Specifically, a single bout of moderate intensity RE facilitated older males' processing speeds in working memory tasks with higher mental loading.

10. General discussion

The current study firstly revealed that acute bouts of moderate intensity RE generally benefited young males' working memory in Study 1; and then demonstrated that the RT protocol selectively facilitated working memory in older males in Study 2. Our results have provided a prima facie case for the differential effect of moderate intensity RE on working memory between young and older males; yet this differential effect of RE should be verified by further studies. Further, our results showed that RTs in the out-of-set probes were generally longer than in the in-set probes across interventions and time stages for both studies. This observed task-condition effect supported the use of the Sternberg paradigm and was in line with previous studies (Chang et al. 2013; Kamijo et al., 2011; Pontifex et al. 2009). Moreover, the facilitated processing speeds in working memory following RE could not be attributed to a speed-accuracy tradeoff strategy because response accuracy after RE was similar to that after reading in both studies.

In contrast to Pontifex et al. (2009), who failed to find the facilitative effect of acute RE on working memory, results in the present study (Study 1) have shown that acute, moderate intensity RE facilitated working memory as assessed 10 min following exercise cessation. As mentioned, two methodological differences may explain the discrepancy in findings between these two studies. First, the current study adopted the RE intensity of 70% 10-RM, which may be closer to the moderate intensity suggested by others

(Chang et al., 2011; Chang & Etnier, 2009) compared with that adopted by Pontifex et al. (2009). Second, the Sternberg paradigm was administered 10 min following exercise, which was consistent with the results of the meta-analytic study of Chang, Labban, et al. (2012) that concluded cognitive performance measured 11–20 min following exercise cessation reveals the largest cognitive benefit of exercise. Further works that directly examine the moderating effects of exercise intensity and time of task administration on the relationship between acute RE and working memory are encouraged.

Results from the two studies (Study 1 and 2) have shown the beneficial effects of RE on working memory in young and older males, respectively. These results have extended findings from previous studies tapping on different aspects of executive function. Specifically, past studies have demonstrated that acute bouts of moderate intensity RE facilitated the inhibitory control aspect of executive function in young and middle-aged adults (Chang & Etnier, 2009; Chang, Tsai, et al., 2014) as well as the planning aspect of executive function in middle-aged adults (Chang et al., 2011; Chang, Ku, et al., 2012). The current findings have therefore added to the knowledge base by revealing the beneficial effects of moderate intensity RE on working memory in young and older males. Findings from Study 2 can be particularly relevant for the elderly since working memory is a critical subcomponent of executive function (Diamond, 2013; Miyake et al., 2000), and its decline in the elderly is one of the main contributors to cognitive degradation that impairs daily living (Nyberg et al., 2012; Park et al., 2002; Schmitter-Edgecombe & Parsey, 2014; Tucker-Drob, 2011).

In addition, though highly speculative, results in the present study may provide a prima facie case for the differential effects of acute, moderate intensity RE on working memory between young and elderly males such that RE generally benefits young males' working memory while older males' working memory is selectively facilitated. We herein recommend that the differential effects of RE on working memory be verified by future works. Our rationales for the recommendation are supported by comparing results across different individual studies. Specifically, previous studies revealed that exercise intervention may result in general cognitive improvements, namely performances on both the lower- and higher-level cognitive aspects can be facilitated, in young adults (Chang & Etnier, 2009; Davranche, Hall, & McMorris, 2009; Hillman, Snook, & Jerome, 2003; Tsai et al., 2014). In contrast, studies of Colcombe and Kramer (2003) and Kramer et al. (1999) indicated that in older adults, exercise intervention may yield the largest benefit for mental processes that require executive ability while there may be a smaller or non-existent benefit for mental processes that require lower-level cognition. Collectively, future works designated to directly examine the potential age-moderating effects can verify our assertion and broaden the knowledge base regarding the relationship between acute RE and working memory.

The cognitive-energetic model postulates that acute, moderate intensity exercise facilitates cognitive performance via optimal arousal levels. Consistent with this hypothesis, our implementation of a moderate-intensity RE intervention induced higher HRs relative to the reading intervention at the treatment and after-treatment stages in both the young and elderly groups, which may be indicative of exercise-induced increases in arousal and possibly lead to improved processing speeds in working memory. Nevertheless, since the cognitive-energetic model was derived mostly from measures undertaken by researchers examining the effects of acute AE on cognition, further acute RE-cognition studies that measure physiological (i.e., HR) and electrophysiological (i.e., CNV amplitude; Kamijo et al., 2004) or biological (i.e., central NE and DA; Berrige et al., 2006) variables that are indicative of arousal changes might be helpful in understanding the arousal theory.

Another speculation in which acute RE improves working memory is exercise-induced cortisol alterations. Cortisol, released in response to stress as the end-product of the hypothalamic-pituitary-adrenocortical-axis (HPA-axis), is believed to modulate cognitive performance. According to psychoneuroendocrinological studies, cortisol secretion may temporarily lead to reduced amygdala inhibition to aversive stimuli and enhance connectivity between the amygdala and the frontoparietal brain regions, thereby resulting in emotional interference and impaired executive control network (Henckens, van Wingen, Joëls, & Fernández, 2012). Additional studies also suggest that cortisol alterations may be negatively associated with executive function performance (Henckens et al., 2012; Lupien & McEwen, 1997; Lyons, Lopez, Yang, & Schatzberg, 2000). However, regarding the effects of acute RE on cortisol alterations, results are equivocal. The study of Arent, Landers, Matt, and Etnier (2005) evidenced that moderate-intensity (70% 10-RM) RE had no effect on saliva cortisol changes. In contrast, Tsai et al. (2014) reported decreased serum cortisol levels following moderate-intensity (50% 1-RM) RE. Correlational analysis in the study further indicated that changes in serum cortisol levels negatively correlated to changes in P3 amplitudes, an indicator for the amount of attentional resources being allocated to external stimuli during cognitive tasks (Tsai, Pan, Cherng, Hsu, & Chiu, 2009). The discrepancy in cortisol response between the two studies may be attributable to the way cortisol was measured. Recent animal study (Hernendez et al., 2014) reported a 10-min time lag between plasma and saliva cortisol in response to acute stress. Plasma cortisol responses were more sensitive to stress and reached peak concentrations 10 min earlier than saliva measures. The authors thereby suggested that caution should be exercised when saliva cortisol samples are used as the only measure of HPA-axis activity. Collectively, despite converging evidence regarding the specific association of cortisol alterations to cognitive functioning, the role of cortisol, particularly serum measures, as the potential mechanism for the facilitative effect of RE on cognitive performance should be further examined.

There are several limitations to the present study that should be acknowledged. First, it may be suggested that improved working memory resulting from the RE treatment might be moderated by participants' cardiovascular fitness, which is not measured by the current study, because the positive relationship between cardiovascular fitness and cognitive performance has been well-documented (Colcombe & Kramer, 2003; Wu & Hillman, 2013). However, studies have shown that the cognitive performance of participants with various cardiovascular fitness levels can all be facilitated by acute exercise (Chang, Labban, et al., 2012; Chang, Chi, et al., 2014). In addition, given the nature of the within-subjects design in the present study, the positive influence of acute RE on working memory may not be confounded by individual differences in cardiovascular fitness levels. Second, the data from the IPAQ in the older adults showed a high inter-subject variability (1984.6 ± 1267.2 METs). Chang et al. (2013) suggested that working memory in older adults aged 65–75 years could be moderated by the amount of physical activity as measured by the IPAQ. However, the nature of a within-subjects design makes differences in physical activity an unlikely explanation for the observed acute effects of RE on working memory.

In conclusion, the current study firstly showed that acute RE (consisting of eight muscle exercises performed in two sets of 10 repetitions at 70% 10-RM for each exercise) could facilitate performances on cognitive tasks with lower- and higher working memory demands in young males; it further revealed that the same RE protocol was effective in promoting performance on cognitive tasks with higher working memory demands in elderly males. Future works designed to replicate our findings in a female population, verifying the moderating roles of exercise intensity, time of task administration, and participants' age on the relationship between acute RE and working memory, are strongly recommended. Additionally, given that executive function declines in the elderly may be domain-specific (Goh, An, & Resnick, 2012), more efforts that aim to extend the cognitive benefits of moderate-intensity RE from working memory to other aspects of executive function in the elderly are encouraged. Finally, future research should consider inter-disciplinary approaches (i.e., neuropsychological, neuroelectric, neuroendocrinological) to more thoroughly address the underlying mechanisms in which acute RE is expected to facilitate cognitive performance.

Acknowledgment

This research was partially supported by a grant from the Ministry of Science and Technology in Taiwan (NSC 102-2410-H-003-139) to Chin-Lung Fang. We gratefully acknowledge all participants for the time they spent in performing the study.

References

Arent, S. M., Landers, D. M., Matt, K. S., & Etnier, J. L. (2005). Dose-response and mechanistic issues in the resistance training and affect relationship. *Journal of Sport and Exercise Psychology, 27*(1), 92–110.
Audiffren, M. (2009). Acute exercise and psychological function: a cognitive-energetics approach. In T. McMorris, P. D. Tomporowski, & M. Audiffren (Eds.), *Exercise and cognitive function* (pp. 3–39). Hoboken, NJ: John Wiley & Sons.
Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews. Neuroscience, 4*(10), 829–839. http://dx.doi.org/10.1038/nrn1201.
Baechle, T. B., & Earle, R. W. (2008). *Essentials of strength training and conditioning* (3rd ed.). Champaign, IL: Human Kinects.
Bauman, A., Bull, F., Chey, T., Craig, C. L., Ainsworth, B. E., Sallis, J. F., &, The IPS group. (2009). The international prevalence study on physical activity: results from 20 countries. *The International Journal of Behavioral Nutrition and Physical Activity, 6*, 21. http://dx.doi.org/10.1186/1479-5868-6-21.
Berrige, C. W., Devibiss, D. M., Andrzejewski, M. E., Arnsten, A. F., Kelley, A. E., Schmeichel, B., et al. (2006). Methylphenidate preferentially increases catecholamine neurotransmission within the prefrontal cortex at low doses that enhance cognitive function. *Biological Psychiatry, 60*(10), 1111–1120.
Borg, G. A. (1982). Psychological bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*(5), 377–381.
Chang, Y. K., Chi, L., Etnier, J. L., Wang, C. C., Chu, C. H., & Zhou, C. (2014). Effect of acute aerobic exercise on cognitive performance: role of cardiovascular fitness. *Psychology of Sport and Exercise, 15*(5), 464–470. http://dx.doi.org/10.1016/j.psychsport.2014.04.007.
Chang, Y. K., Chu, I. H., Chen, F. T., & Wang, C. C. (2011). Dose-response effect of acute resistance exercise on Tower of London in middle-aged adults. *Journal of Sports and Exercise Psychology, 33*(6), 866–883.
Chang, Y. K., & Etnier, J. L. (2009). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology, 31*(5), 640–656.
Chang, Y. K., Huang, C. J., Chen, K. F., & Hung, T. M. (2013). Physical activity and working memory in healthy older adults: an ERP study. *Psychophysiology, 50*(11), 1174–1182.
Chang, Y. K., Ku, P. W., Tomporowski, P. D., Chen, F. T., & Huang, C. C. (2012). Effects of acute resistance exercise on late-middle-age adults' goal planning. *Medicine and Science in Sports and Exercise, 44*(9), 1773–1779. http://dx.doi.org/10.1249/MSS.0b013e3182574e0b.
Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Research, 1453*, 87–101. http://dx.doi.org/10.1016/j.brainres.2012.02.068.
Chang, Y. K., Pan, C. Y., Chen, F. T., Tsai, C. L., & Huang, C. C. (2012). Effect of resistance-exercise training on cognitive function in healthy older adults: a review. *Journal of Aging and Physical Activity, 20*(4), 497–517.
Chang, Y. K., Tsai, C. L., Huang, C. C., Wang, C. C., & Chu, I. H. (2014). Effects of acute resistance exercise on cognition in late middle-aged adults: general or specific cognitive improvement? *Journal of Science and Medicine in Sport, 17*(1), 51–55. http://dx.doi.org/10.1016/j.jsams.2013.02.007.
Chun, M. M., Golomb, J. D., & Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annual Review of Psychology, 62*, 73–101. http://dx.doi.org/10.1146/annurev.psych.093008.100427.
Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14*(2), 125–130.
Davranche, K., Hall, B., & McMorris, T. (2009). Effect of acute exercise on cognitive control required during an Eriksen flanker task. *Journal of Sport and Exercise Psychology, 31*(5), 628–639.
Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. http://dx.doi.org/10.1146/annurev-psych-113011-143750.
Etnier, J. L., & Chang, Y. K. (2009). The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *Journal of Sport and Exercise Psychology, 31*(4), 469–483.
Finnigan, S., O'Connell, R. G., Cummins, T. D. R., Broughton, M., & Robertson, I. H. (2011). ERP measures indicate both attention and working memory encoding decrements in aging. *Psychophysiology, 48*(5), 601–611. http://dx.doi.org/10.1111/j.1469-8986.2010.01128.x.
Goh, J. O., An, Y., & Resnick, S. M. (2012). Differential trajectories of age-related changes in components of executive and memory processes. *Psychology and Aging, 27*(3), 707–719. http://dx.doi.org/10.1037/a0026715.
Henckens, M. J., van Wingen, G. M., Joëls, M., & Fernández, G. (2012). Time-dependent effects of cortisol on selective attention and emotional interference: a functional MRI study. *Frontiers in Integrative Neuroscience, 6*(66). http://dx.doi.org/10.3389/fnint.2012.00066.
Hernendez, C. E., Thierfelder, T., Svennersten-Sjaunja, K., Berg, C., Orihuela, A., & Lidfors, L. (2014). Time lag between peak concentrations of plasma and salivary cortisol following a stressful procedure in dairy cattle. *Acta Veterinaria Scandinavica, 56*(1), 1–17. http://dx.doi.org/10.1186/s13028-014-0061-3.
Heyman, T., Van Rensbergen, B., Storms, G., Hutchison, K. A., & De Deyne, S. (2015). The influence of working memory load on semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(3), 911–920. http://dx.doi.org/10.1037/xlm0000050.
Hillman, C. H., Snook, E. M., & Jerome, G. J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology, 48*(3), 307–314.
Hogan, C. L., Mata, J. L., & Carstensen, L. L. (2013). Exercise holds immediate benefits for affect and cognition in younger and older adults. *Psychology and Aging, 28*(2), 587–594. http://dx.doi.org/10.1037/a0032634.
Hogervorst, E. (2013). Effects of gonadal hormones on cognitive behaviour in elderly men and women. *Journal of Neuroendocrinology, 25*(11), 1182–1195. http://dx.doi.org/10.1111/jne.12080.
Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Kida, T., Higashiura, T., et al. (2004). Changes in arousal level by differential exercise intensity. *Clinical Neurophysiology, 115*(12), 2693–2698. http://dx.doi.org/10.1016/j.clinph.2004.06.016.
Kamijo, K., Pontifex, M. B., O'Leary, K. C., Schudder, M. R., Wu, C. T., Castelli, D. M., et al. (2011). The effects of an afterschool physical activity program on working memory in preadolescent children. *Developmental Science, 14*(5), 1046–1058. http://dx.doi.org/10.1111/j.1467-7687.2011.01054.x.
Kraemer, W. J., Staron, R. S., Hagerman, F. C., Hikida, R. S., Fry, A. C., Gordon, S. E., et al. (1998). The effects of short-term resistance training on endocrine function in men and women. *European Journal of Applied Physiology and Occupational Physiology, 78*(1), 69–76.
Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., et al. (1999). Aging, fitness, and neurocognitive function. *Nature, 400*(6743), 418–419. http://dx.doi.org/10.1038/22682.
Kray, J. L., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15*(1), 126–147.
Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. *Brain Research, 1341*, 12–24. http://dx.doi.org/10.1016/j.brainres.2010.03.091.
Liou, Y. M., Jwo, C. J. C., Yao, K. G., Chiang, L. C., & Huang, L. H. (2008). Selection of appropriate Chinese terms to represent intensity and types of physical activity terms for use in the Taiwan version of IPAQ. *The Journal of Nursing Research, 16*(4), 252–263.
Lupien, S. J., & McEwen, B. S. (1997). The acute effects of corticosteroids on cognition: integration of animal and human model studies. *Brain Research Reviews, 24*(1), 1–27. http://dx.doi.org/10.1016/S0165-0173(97)00004-0.
Lyons, D. M., Lopez, J. M., Yang, C., & Schatzberg, A. F. (2000). Stress-level cortisol treatment impairs inhibitory control of behavior in monkeys. *The Journal of Neuroscience, 20*(20), 7816–7821.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49–100.
Nagamatsu, L. S., Handy, T. C., Hsu, C. L., Voss, M., & Liu-Ambrose, T. (2012). Resistance training promotes cognitive and functional brain plasticity in seniors with probable mild cognitive impairment. *Archives of Internal Medicine, 172*(8), 666–668. http://dx.doi.org/10.1001/archinternmed.2012.379.
Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences, 16*(5), 292–305. http://dx.doi.org/10.1016/j.tics.2012.04.005.
Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299–320. http://dx.doi.org/10.1037/0882-7974.17.2.299.
Pelosi, L., Hayward, M., & Blumhardt, L. (1995). Is "memory-scanning" time in the Sternberg paradigm reflected in the latency of event-related potentials? *Electroencephalography and Clinical Neurophysiology, 96*(1), 44–55.
Pelosi, L., Hayward, M., & Blumhardt, L. (1998). Which event-related potentials reflect memory processing in a digit-probe identification task? *Cognitive Brain Research, 6*(3), 205–218.
Pontifex, M. B., Hillman, C. H., Fernhall, B., Thompson, K., & Valentini, T. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine and Science in Sports and Exercise, 41*(4), 927–934. http://dx.doi.org/10.1249/

MSS.0b013e3181907d69.
Rubia, K., Hyde, Z., Halari, R., Giampietro, V., & Smith, A. (2010). Effects of age and sex on developmental neural networks of visual-spatial attention allocation. *NeuroImage, 51*(2), 817–827. http://dx.doi.org/10.1016/j.neuroimage.2010.02.058.
Schmitter-Edgecombe, M., & Parsey, C. M. (2014). Assessment of functional change and cognitive correlates in the progression from healthy cognitive aging to dementia. *Neuropsychology, 28*(6), 881–893. http://dx.doi.org/10.1037/neu0000109.
Sternberg, S. (1966). High-speed scanning of human memory. *Science, 153*(3736), 652–654.
Tays, W. J., Dywan, J., Capuana, L. J., & Segalowitz, S. J. (2011). Age-related differences during simple working memory decisions: ERP indices of early recognition and compensation failure. *Brain Research, 1393*, 62–72. http://dx.doi.org/10.1016/j.brainres.2011.04.006.
Tsai, C. L., Pan, C. Y., Cherng, R. J., Hsu, Y. W., & Chiu, H. H. (2009). Mechanisms of deficit of visuospatial attention shift in children with developmental coordination disorder: a neurophysiological measure of the endogenous Posner paradigm. *Brain and Cognition, 71*(3), 246–258. http://dx.doi.org/10.1016/j.bandc.2009.08.006.
Tsai, C. L., Wang, C. H., Pan, C. Y., Chen, F. C., Huang, T. H., & Chou, F. Y. (2014). Executive function and endocrinological responses to acute resistance exercise. *Frontiers in Behavioral Neuroscience, 8*, 262. http://dx.doi.org/10.3389/fnbeh.2014.00262.
Tucker-Drob, E. M. (2011). Neurocognitive functions and everyday functions change together in old age. *Neuropsychology, 25*(3), 368–377. http://dx.doi.org/10.1037/a0022348.
Williams, M. A., Haskell, W. L., Ades, P. A., Amsterdam, E. A., Bittner, V., Franklin, B. A., et al. (2007). Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on clinical cardiology and council on nutrition, physical activity, and metabolism. *Circulation, 116*(5), 572–584.
Wu, C. T., & Hillman, C. H. (2013). Aerobic fitness and the attentional blink in preadolescent children. *Neuropsychology, 27*(6), 642–653. http://dx.doi.org/10.1037/a0034025.