Dose-Response Effect of Acute Resistance Exercise on Tower of London in Middle-Aged Adults

Yu-Kai Chang, I-Hua Chu, Feng-Tzu Chen, and Chun-Chih Wang

The present research attempts to evaluate the dose-response relationship between acute resistance exercise and planning. Seventeen participants performed the Tower of London (TOL) in control condition and three different exercise intensity conditions (40%, 70%, and 100% 10-repetition maximal) in a counterbalanced order. The results revealed positive effects of an acute bout of resistance exercise on the TOL. Specifically, a curvilinear trend was observed between exercise intensity and TOL scores that measured performances of “correct” and “move,” where moderate intensity demonstrated the most optimal performance compared with the other conditions. None of these differences were found in TOL scores that measure performances of “violation” and “planning speed.” These results suggest that acute moderate intensity resistance exercise could facilitate planning-related executive functions in middle-aged adults.

Keywords: acute exercise, executive function, plan, resistance exercise, strength training

Cognitive ability is important for daily life and is recognized as a main component of the health-related quality of life. However, cognitive ability has been demonstrated to decline with age. Salthouse (2003b) indicates that, with the exception of vocabulary, cognitive abilities in reasoning, memory, and speed decline with age ($r = -.43$ to $-.48$). In addition, that study reports that the highest and lowest cognitive scores were found in adults in their early 20s and 70s, respectively, and the declining trend was linear between these two age categories. Similar results have been reported in other studies (Park et al., 2002; Salthouse, 2003a).

Fortunately, many factors have been confirmed to delay or even eliminate cognitive decline with age. Using a structural equation model, Albert et al. (1995) reported that four endogenous variables, including strenuous activity, can directly...
predict cognitive changes in the later years of life. Recently, studies focused on the effects of exercise on cognition have provided further evidence that both chronic exercise (long-term participation in exercise) and acute exercise (a single bout of exercise) benefit cognitive performance across age groups (see reviews in Angelvaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006; Lambourne & Tomporowski, 2010).

Although substantial evidence has been presented for the beneficial effects of exercise on cognition, many studies have been limited in their scope. For instance, most studies have focused on the college-aged or older populations (Audiffren, Tomporowski, & Zagrodnik, 2009; Barella, Etnier, & Chang, 2010; Davranche & Audiffren, 2004; Hillman, Snook, & Jerome, 2003), and only recently, a few studies have targeted middle-aged adults (Chang & Etnier, 2009a; Kamijo et al., 2009; Netz, Tomer, Axelrad, Argov, & Inbar, 2007). The middle-aged population may be particularly important to examine because they play the significant role with respect to the productivity of a society.

A meta-analytic review conducted by Colcombe and Kramer (2003) indicates that the effect of chronic exercise on cognition is selective. Although exercise benefits all types of cognitive functions significantly, exercise has a greater positive effect on executive-related cognitive functions than it does on speed, spatial cognition, or control-related cognition. What is unknown, however, is whether acute exercise in particular can improve executive function.

Hillman et al. (2003) examined the effects of acute aerobic exercise on executive function assessed by the Erickson flanker task and event-related potentials. They indicated that acute moderate exercise results in larger P3 amplitude and shorter P3 latency in incompatible conditions, suggesting that acute exercise benefits executive functions via better attentional relocation and information processing speed. Similar positive effects on executive function following acute exercise were found when using other types of executive function assessments (e.g., a random number generation task) (Audiffren et al., 2009; Joyce, Graydon, McMorris, & Davranche, 2009).

A number of studies have focused on older and middle-aged adults and have reported somewhat contradictory results (Barella et al., 2010; Kamijo et al., 2009; Netz et al., 2007). Kamijo et al. (2009) examined the effects of acute aerobic exercise intensity on executive function in both younger and older adults. The results indicate that exercise of light or moderate intensity improves executive function for both age groups; however, there were differences in the underlying mechanisms, where younger adults increased attentional allocation and older adults increased information processing speed. Similarly, Netz et al. (2007) assessed the effects of exercise intensity on executive function using the Digit Span Forward and Alternate Uses Tests. The results indicated that acute exercise sessions (both 60% heart rate reserve/HRR and 70% HRR groups) only improved executive function assessment (Alternate Uses Test). In contrast, Barella et al. (2010) observed an improved Stroop effect in 70-year-old adults after 60% HRR exercises which consisted of 20 min of walking, but the benefit was limited to the Stroop color condition, an indication of nonexecutive function.

Clearly, the effect of acute exercise on executive function among middle-aged and older-adult is still under debate. Recently, Etnier and Chang (2009) provided recommendations for examining the inconsistent results. They suggested that,
because executive function is an umbrella or “meta-” term and includes a variety of basic cognitive functions (e.g., scheduling, planning, working memory, interference control, task coordination), future research should provide a definition for a specific type of executive function as well as careful consideration of which measurements to examine. Moreover, Etnier and Chang identified the most commonly used executive function tasks (e.g., Stroop Test, Trial Making Test, Tower of London) based on recent neuropsychological reviews, and they noted that these tasks are not used frequently in the field of physical activity and cognition.

Given that there is a general consensus among researchers that executive function involves planning ability (Kramer et al., 1999; Lezak, Howieson, Loring, Hannay, & Fischer, 2004; Rabbitt, 1997; Salthouse, 2007), the current study focuses on this specific type of executive function. We used Tower of London (TOL), one of the most popular neuropsychological assessments for executive function, to examine the planning ability. The TOL has been frequently used to measure planning and problem solving in both clinical and nonclinical populations (Berg & Byrd, 2002; Berg, Byrd, McNamara, & Case, 2010; Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008; Unterrainer et al., 2004). It was modified from the Tower of Hanoi task, and was originally developed to assess planning deficits in patients with frontal lobe damage (Shallice, 1982). To perform the TOL effectively, goals and subgoals need to be determined before starting. Specifically, participants are required to generate and maintain goal and subgoal representations (Polk, Simen, Lewis, & Freedman, 2002), conduct higher-level programming, or maintain a sequence of operations (e.g., select, execute, evaluate, and accept or withdraw) (Dehaene & Changeux, 1997). Because these executive controls are required by the participant during the TOL process, planning ability is therefore assessed.

Another issue that may contribute to the relationship between acute exercise and executive function is the type of exercise intervention. The majority of studies have studied the effects of aerobic types of exercise, typically using either cycling or treadmill exercises (for a review, see Lambourne & Tomporowski, 2010) and only a few works have been examined the effects of acute resistance exercise on cognition (Chang & Etnier, 2009a, 2009b). Given that resistance exercise has been demonstrated to improve health-related physical fitness and to protect against health-related diseases, such as osteoporosis, low back pain, hypertension, diabetes, and abnormal blood lipids (Kraemer, Ratamess, & French, 2002; Winett & Carpinelli, 2001), further studies focusing on this type of exercise are required. Chang and Etnier (2009a) examined the effects of an acute session of resistance exercise on executive functions assessed by the Stroop and Trial Making Tests in middle-aged adults. The results indicated that acute resistance exercise was beneficial to processing speed and executive function assessed by the Stroop Test. These results provide evidence that in addition to aerobic exercise, resistance exercise has a positive effect on executive function.

One line of research has been to better understand the dose-response of acute exercise on cognition. Results of these studies have been mixed in that some have concluded that there is a curvilinear or inverted-U relationship (Aks, 1998; Arent & Landers, 2003; Brisswalter, Durand, Delignieres, & Legros, 1995; Chmura, Nazar, & Kaciuba-Uscilko, 1994; McMorris & Graydon, 2000), while others have concluded that the relationship is linear (Davranche & Audiffren, 2004; McMorris & Graydon, 2000). The explanation for these mixed results may be related to
differences in task complexity. Arent and Landers (2003) suggested that a linear relationship may be appropriate for explaining the exercise intensity-performance relationship for the components of a task that require more motor or peripheral processes. An inverted-U relationship, however, may be appropriate for the components of the task that require greater cognitive or central processes. Thus, it may be that the dose-response relationship between exercise intensity and cognitive performance is dependent upon the demands of the particular cognitive task or executive function being assessed.

Chang and Etnier (2009b) recently used a resistance exercise to further confirm the dose-response relationship between exercise intensity and different types of executive function. In that study, participants were randomly assigned into control, 40%, 70% or 100% 10 repetition maximal resistance (10-RM) groups. Participants were instructed to perform executive function testing via the Stroop Test and the Paced Auditory Serial Addition Task (PASAT). A positive linear trend correlating nonexecutive function and exercise intensity was detected. In addition, an inverted-U trend was found to correlate performance of executive function and exercise intensity, wherein the 70% 10-RM group showed the highest scores. It was encouraging that a dose-response between resistance exercise and executive function was identified; however, that study was one of few to have examined the issue. Moreover, these studies have generally focused on college-aged adults and specific types of tasks, so they cannot be generalized to other populations or overall executive function.

In summary, it is important to further examine the effects of acute resistance exercise intensity on executive function in middle-aged adults to advance both our theoretical and practical understanding. Therefore, the primary purpose of the current study is to explore the effects of acute resistance exercise on executive functions in middle-aged adults. More specifically, the dose-response effect of four different intensities of acute resistance exercise (control, 40%, 70%, and 100% 10-RM) on planning was examined in middle-aged adults as assessed by TOL performance. Given that the effects of acute resistance exercise on executive functions has been explored using other types of neuropsychological assessments (Chang & Etnier, 2009a), it was predicted that submaximal intensities would elicit better TOL performance in terms of increasing the number of correctly performed tests and decreasing the number of moves. It was also predicted that submaximal intensities would improve executive processing time when compared with control and 100% 10-RM conditions. In addition, the current study extends prior research examining the dose-response relationship between acute exercise and executive function in the young population (Chang & Etnier, 2009b) and predicts that middle-aged adults exhibit the most executive function enhancement in the 70% 10-RM condition.

Method

Participants

Seventeen community-dwelling adults aged 40–65 years were recruited. The number of participants was determined using a one-way ANOVA power analysis with effect size $f = 0.30$, power $= 0.8$ and alpha at .05 (Chang & Etnier, 2009a). Each participant provided a written informed consent approved by the National Taiwan Sport University Institutional Review Board before participation. An initial screening
criterion was administered using the Physical Activity Readiness Questionnaire (PAR-Q) to ensure that it was safe for the participant to perform this series of resistance exercises. This approach follows the guidelines of the American College of Sports Medicine (2010). Demographic information, level of physical activity and experience in resistance exercise were assessed using a demographic questionnaire and the International Physical Activity Questionnaire (IPAQ). The IPAQ was developed as an international surveillance tool to measure physical activity level cross-nationally (Bauman et al., 2009; Craig et al., 2003), and the Taiwan version of the IPAQ has been established by Liou, Jwo, Yao, Chiang, and Huang (2008). Participant demographic and physiological characteristics are presented in Table 1.

### Table 1 Descriptive Data for Participant Demographic and Physiological Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Female M (SD)</th>
<th>Male M (SD)</th>
<th>Total M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>13</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Age (year)</td>
<td>56.00 (8.96)</td>
<td>53.50 (10.7)</td>
<td>55.41 (9.10)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.46 (7.68)</td>
<td>170.25 (4.50)</td>
<td>163.53 (7.92)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.25 (10.42)</td>
<td>76.25 (6.34)</td>
<td>67.07 (10.79)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.64 (3.78)</td>
<td>26.33 (2.30)</td>
<td>25.04 (3.50)</td>
</tr>
<tr>
<td>IPAQ (METs)</td>
<td>766.08 (765.09)</td>
<td>1292.50 (919.47)</td>
<td>889.94 (806.55)</td>
</tr>
<tr>
<td>HRbaseline (bpm)</td>
<td>68.39 (10.93)</td>
<td>67.25 (3.59)</td>
<td>68.12 (9.61)</td>
</tr>
<tr>
<td>Right dumbbell curl (lb)</td>
<td>17.12 (4.59)</td>
<td>28.25 (3.50)</td>
<td>19.73 (6.47)</td>
</tr>
<tr>
<td>Left dumbbell curl (lb)</td>
<td>15.35 (4.38)</td>
<td>34.00 (4.62)</td>
<td>19.74 (9.22)</td>
</tr>
<tr>
<td>Right dumbbell front raises (lb)</td>
<td>14.00 (4.06)</td>
<td>22.75 (6.13)</td>
<td>16.06 (5.84)</td>
</tr>
<tr>
<td>Left dumbbell front raises (lb)</td>
<td>14.46 (4.72)</td>
<td>24.00 (8.25)</td>
<td>16.71 (6.84)</td>
</tr>
<tr>
<td>Right dumbbell rows (lb)</td>
<td>35.31 (4.87)</td>
<td>54.75 (3.50)</td>
<td>39.88 (9.61)</td>
</tr>
<tr>
<td>Left dumbbell rows (lb)</td>
<td>35.92 (4.65)</td>
<td>53.00 (0.00)</td>
<td>39.94 (8.48)</td>
</tr>
<tr>
<td>Dumbbell fly (lb)</td>
<td>22.00 (7.16)</td>
<td>36.00 (4.00)</td>
<td>25.29 (8.89)</td>
</tr>
<tr>
<td>Shoulder press (lb)</td>
<td>14.69 (5.59)</td>
<td>23.25 (6.24)</td>
<td>16.71 (6.69)</td>
</tr>
<tr>
<td>Dumbbell upright row (lb)</td>
<td>18.65 (3.85)</td>
<td>34.00 (4.62)</td>
<td>22.26 (7.75)</td>
</tr>
</tbody>
</table>

*Note.* HR	extsubscript{baseline} was assessed at the baseline section.

### Resistance Exercise Design

The resistance exercise protocol was selected based on the protocol used by Chang and Etnier (2009b), who examined dose-response relationships between resistance exercise and cognitive performance using exercise intensities of 40%, 70%, and 100% 10-RM. Using heart rate and rating of perceived exertion, these intensities were confirmed to represent low, moderate and high exercise intensities, respectively. The designation 10-RM indicates that the participant can lift the load 10 times before exhaustion.
The approach used to identify the 10-RM for each muscle exercise is based on the 10-RM testing protocol (Baechle & Earle, 2000). After a warm-up with light resistance exercise, the participants were instructed to change the load and to continue the testing process until they reached a load level that they would be able to lift a maximum of 10 repetitions. Generally, the instructor was able to adjust the loads so that the 10-RM could be measured within four testing sets. The following nine muscle exercises were selected: right and left dumbbell curl, right and left dumbbell front raises, right and left dumbbell rows, dumbbell fly, shoulder press, and dumbbell upright row. The load for each of the nine muscle exercises was determined using the same protocol.

With respect to the resistance exercise intervention protocol, the use of 10 repetitions was selected to be within the 8–12 repetitions per set suggested by the ACSM for increasing muscular strength, endurance, and hypertrophy. The resistance exercise session of the present intervention protocol included two sets of 10 repetitions for each of the nine muscle exercises. The rest period between sets and between exercises was 1 min.

Exercise Intensity Manipulation Check

Heart Rate (HR). The HR was monitored by short-range radio telemetry devices (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland). The HR monitor consists of an elastic band strapped around the chest to hold a rubber pad (containing the HR measuring device and transmitter) in place just below the sternum together with a wristband receiver. The participant’s HR was displayed on the face of the wristband receiver, and data from the HR monitor was recorded at 1-min intervals. Four HR variables were identified: HRbaseline, HR at the baseline session; HRpre, HR assessed before each treatment intervention (control, 40%, 70%, and 100% 10-RM); and HRaverage, the average HR during the treatment session.

Rating of Perceived Exertion (RPE). The RPE scale was developed by Borg (1982) and provides a subjective rating of an individual’s perception of effort during exercise. The original Borg scale has a range from 6 to 20. Scores from 7 to 11 are recognized as “very, very light to fairly light”; scores from 13 to 14 are recognized as “somewhat hard”; scores from 15 to 19 are recognized as “hard to very, very hard”; and score of 20 is recognized as “maximal exertion.” The RPE value represents the average of the RPE scores during the treatment session for each individual.

Tower of London (TOL). Of the several TOL versions that have been designed, the current study used the TOLDX (Culbertson & Zillmer, 2005). The TOL apparatus consists of two identical wooden boards (30 × 7 × 10 cm), one for the participant and one for the examiner, and two sets of three beans (blue, green, and red). Each board consists of three vertical pegs with graded heights. The tallest peg (Peg 1) can hold three beans, the middle peg (Peg 2) can fit two beans, and the shortest peg (Peg 3) can fit a single bean. A wooden board was given to the participant with a standard start configuration, in which Peg 1 has two beans (red on top of green) and Peg 2 has the blue bean. A second wooden board was controlled by the examiner, who was given 10 prescribed goal configurations, or test problems. The 10 test problems (adult version) have differing levels of difficulty, as determined by the
minimum number of moves (from two to seven) required to complete the task (see Figure 1). Participants were instructed to move beans from the start configuration to the goal configuration using as few moves as possible without violating TOL rules. Administration of the TOL took 25–30 min. The test–retest reliabilities were acceptable ($r = .24–.80$) (Culbertson, Moberg, Duda, Stern, & Weintraub, 2004; Culbertson & Zillmer, 1998).

Figure 1 — An example Tower of London Task with start configuration and goal configuration with five moves.

Recent research has determined that the TOL is multifaceted and has suggested that a greater number of indicators can be analyzed (Berg et al., 2010). Seven performance scores were computed based on the TOL technical manual: total move score, total correct score, rule violation score, time violation score, total initial time, total executive time, and total planning-solving time (Culbertson & Zillmer, 2005).

**Procedures**

Participants were asked to come to the laboratory for five separate testing days, each of which were at least 48 hr apart. During Day 1, the participant was presented with a brief introduction to the study by the investigator. The participant also filled out the consent form, a demographic questionnaire, the PAR-Q, and the IPAQ.
The PAR-Q was used as an initial screening criterion, and the IPAQ was used to determine the amount of physical activity performed weekly. After completing the questionnaires, participants were instructed to attach the HR monitor and to sit quietly in a comfortable chair in a dimly lit room for 15 min. At the conclusion of the 15-min period, HRbaseline was assessed and the participant’s 10-RM for each of the nine muscle exercises was determined.

All of the participants then came to the laboratory on four separate days scheduled according to a counterbalanced design to minimize any order or learning effects (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). During each visit, participants were asked to sit quietly in a comfortable chair in a dimly lit room for 15 min, after which HRpre was assessed. The participants were then assigned to either the control condition or one of three different resistance exercise intensity conditions. In the exercise conditions, participants performed two sets of 10 repetitions for each of the nine muscle exercises at 40%, 70%, or 100% 10-RM. Heart rate and RPE were assessed at the end of each of the nine muscle exercises. Participants in the control condition were asked to watch a video on resistance exercise training for an amount of time similar to what was needed for the treatment condition to perform the resistance exercise (determined through pilot testing). Following completion of the assigned treatment condition, the TOL was performed. Each visit lasted approximately an hour and a half.

**Statistical Analyses**

To analyze the exercise intensity manipulation, statistical analyses of HRpre, HRaverage, and RPE were performed. A two-way repeated measures (2 × 4, Time × Condition) ANOVA was used to determine the effect of exercise intensity on HRpre and HRaverage. Wilks’s lambda statistic was employed for within-design assessments and a Greenhouse–Geisser correction was used when Mauchly’s test of sphericity was violated. In addition, simple main effects analyses were performed when there was a significant interaction of time and condition. One-way repeated-measures ANOVAs and post hoc analysis were conducted for the effect of RPE.

With respect to TOL scores, one-way repeated-measures ANOVAs were separately conducted for seven TOL scores. Post hoc analyses were further used to identify the differences between the four exercise intensity conditions when significant effects were identified. A Bonferroni adjustment was applied for all statistical tests. Lastly, trend analyses were computed for HR, RPE, and TOL scores, to identify the dose-response trend between exercise intensity and cognitive performance. Estimates of effect size and partial eta-square ($\eta_p^2$) were reported for significant effects. An alpha of .05 was used as the level of statistical significance for all statistical analyses.

**Results**

**Exercise Manipulation Check**

A 2 × 4 repeated-measures ANOVA revealed that there were main effects for time, $F(1, 16) = 470.37, p < .001, \eta_p^2 = 0.97$; exercise condition, $F(3, 48) = 86.67, p < .001, \eta_p^2 = 0.84$; and an interaction between condition and time, $F(3, 48) = 191.63, p < .001, \eta_p^2 = 0.92$. 
Follow-up simple main effect analyses were performed. The results revealed that a significant time effect was found for three exercise conditions, \( F(1, 16) > 166.83, p < .001, \eta_p^2 > .91 \), but not in control condition. In addition, \( \text{HR}_{\text{average}} \) in each condition was significant difference from the other conditions, whereas no difference was found in \( \text{HR}_{\text{pre}} \) (see Figure 2). In support of this finding, trend analysis indicated there was a significant linear trend, \( F(1, 16) = 485.15, p < .001, \eta_p^2 = 0.97 \).

![Heart rate fluctuation based upon different exercise intensities.](image)

**Figure 2** — Heart rate fluctuation based upon different exercise intensities.

With respect to RPE, one-way repeated ANOVA revealed that there were significant differences between the three exercise conditions, \( F(2, 32) = 177.97, p < .001, \eta_p^2 = 0.92 \), where the RPE in each condition was significantly different from the other conditions (see Table 2). Trend analysis indicated the presence of a significant linear trend \( F(1, 16) = 234.43, p < .001, \eta_p^2 = 0.94 \).

**TOL Measure Scores**

**Total Correct Score and Total Move Score.** One-way repeated-measures ANOVA revealed that the total correct score was significantly different among the four conditions, \( F(3, 48) = 3.65, p < .05, \eta_p^2 = 0.19 \). Post hoc analysis revealed that the 40% and 70% 10-RM conditions had higher correct scores than the other two conditions. In support of this finding, trend analysis indicated that, rather than a linear or cubic trend, there was a significant curvilinear/U-shaped trend, \( F(1, 16) = 9.12, p < .001, \eta_p^2 = 0.36 \) (see Figure 3a). Means and standard deviations for total TOL measure scores are summarized in Table 2.
### Table 2  Means and Standard Deviations for Exercise Manipulation Check and TOL Measure Scores

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>40% 10-RM</th>
<th>70% 10-RM</th>
<th>10% 10-RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>HR&lt;sub&gt;pre&lt;/sub&gt; (bpm)</td>
<td>75.47 (9.45)</td>
<td>76.71 (10.59)</td>
<td>75.35 (10.29)</td>
<td>73.82 (10.54)</td>
</tr>
<tr>
<td>HR&lt;sub&gt;average&lt;/sub&gt; (bpm)</td>
<td>70.82 (9.40)</td>
<td>95.80 (14.63)</td>
<td>107.72 (15.83)</td>
<td>117.76 (16.11)</td>
</tr>
<tr>
<td>RPE&lt;sub&gt;average&lt;/sub&gt;</td>
<td>N/A</td>
<td>11.81 (2.58)</td>
<td>15.43 (2.30)</td>
<td>18.51 (1.62)</td>
</tr>
<tr>
<td>Total correct score</td>
<td>6.94 (1.95)</td>
<td>7.88 (1.93)</td>
<td>8.59 (1.50)</td>
<td>7.41 (1.97)</td>
</tr>
<tr>
<td>Total move score</td>
<td>14.29 (11.12)</td>
<td>10.29 (11.28)</td>
<td>6.00 (7.47)</td>
<td>13.65 (14.22)</td>
</tr>
<tr>
<td>Rule violation score</td>
<td>0.18 (0.39)</td>
<td>0.6 (0.24)</td>
<td>0.00 (0.00)</td>
<td>0.12 (0.33)</td>
</tr>
<tr>
<td>Time violation score</td>
<td>0.12 (0.33)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>0.59 (0.24)</td>
</tr>
<tr>
<td>Total initial time</td>
<td>31.09 (3.77)</td>
<td>34.27 (4.90)</td>
<td>35.00 (4.47)</td>
<td>33.57 (4.37)</td>
</tr>
<tr>
<td>Total executive time</td>
<td>113.59 (47.02)</td>
<td>102.19 (29.20)</td>
<td>98.42 (33.70)</td>
<td>107.96 (33.55)</td>
</tr>
<tr>
<td>Total planning-solving time</td>
<td>144.68 (54.14)</td>
<td>136.46 (39.17)</td>
<td>133.48 (43.52)</td>
<td>141.53 (33.91)</td>
</tr>
</tbody>
</table>

*Note. HR<sub>pre</sub> = HR assessed before each treatment interventions; HR<sub>average</sub> = HR assessed during the each treatment session; RPE<sub>average</sub> = RPE assessed during the each treatment session.*
Figure 3 — Dose-response relationship between TOL measure scores and acute resistance exercise intensity. (a) Total correct score and (b) total move score.
One-way repeated-measures ANOVA analyses revealed that total move scores were significantly different among the four conditions, $F(3, 48) = 2.81, p < .05, \eta^2_p = 0.15$. The results of post hoc analysis revealed that participants in the 40% and 70% 10-RM conditions had fewer correct scores than those in the other two conditions. In support of this finding, the results of trend analysis indicated that, rather than a linear or cubic trend, there was a significant curvilinear/U-shaped trend, $f(1, 16) = 9.12, p < .001, \eta^2_p = 0.32$ (see Figure 3b).

**Rule Violation Score and Time Violation Score.** With respect to two violation scores, one-way repeated-measures ANOVA revealed that there was no significant difference in rule violation scores or time violation score, $F(3, 48) > 1.27, p > .05$.

**Total Initial Time, Total Executive Time, and Total Planning-Solving Time Scores.** Similar to the findings for violation scores, none of these time-related scores (initial time, executive time, and planning solving) were significantly different between conditions, $F(3, 48) > 0.36, p > .05$.

**Discussion**

This study examined the effects of acute resistance exercise on executive function, specifically the dose-response effect of resistance exercise on the TOL, a task related to planning of executive functions. With appropriate manipulation of exercise intensity as assessed by HR and RPE, the main findings revealed that participants in the 40% and 70% 10-RM conditions had better performance in total correct score and total move score, suggesting that resistance exercise of moderate intensity has a beneficial effect when compared with the control and 100% 10-RM conditions. Moreover, no differences in violation- or planning speed–related scores were observed among the four conditions, suggesting that acute resistance exercise may not influence these aspects of planning.

Study conducted by Netz et al. (2007) is one of few acute exercise and cognition studies that has been targeted on middle-aged adults. They indicated that acute moderate intensity exercise specifically improves cognitive flexibility, an aspect of executive function, in the population. Recently, Lambourne and Tomporowski (2010) further indicated that more research is necessary to shift attention from young adults to middle- and older-aged populations. The present study is in accordance with these views and extends the current knowledge by presenting that acute exercise benefits planning aspects of executive functions in middle-aged adults.

Etnier and Chang (2009) state that executive function is a meta- or higher-level cognitive ability involving multiple cognitive subcomponents, and they further propose that application of a variety of neuropsychological assessments is required to advance our understanding of the different components of executive function. The present study followed this line of thought and found improved performance in total correct score and total move score of the TOL. The total correct score, which is the number of tests completed in the minimum number of moves, is related to the mental maintenance of move sequences, a process that guides planning and problem solving. Total move score, which is the difference between actual moves and the minimum number of moves, has been linked to attentional allocation, working memory, and mental flexibility. Collectively, the beneficial effects of acute resistance
exercise reflects the improved performance of multiple subcognitive functions, a finding that confirms previous studies that used inhibition-related tasks (e.g., the flanker task, the go/no go task, the Stroop test, and the Simon task) (Chang & Etnier, 2009b; Davranche & McMorris, 2009; Hillman et al., 2003; Kamijo et al., 2004).

However, the effects of acute exercise on these neuropsychological assessments may be based on a different underlying system. Research has indicated that cognitive control processes can act through two dissimilar dimensions, the evaluative system and the regulative system (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The evaluative system is related to the monitoring of the conflict between stimulus and task during cognitive processing and provides feedback to adapt to specific task demands. Neuroimaging techniques have indicated that the anterior cingulate cortex may be involved in the activation of the evaluative system. Previous studies analyzing the relationship between exercise and executive function have applied inhibitory tasks that could be related to the evaluative system (Hillman, Pontifex, & Themanson, 2009; Hillman et al., 2003; Kamijo et al., 2004).

In contrast, the regulative system is related to top-down functions during information processing, and the dorsolateral prefrontal cortex has been implicated in these functions. Using functional magnetic resonance imaging, Newman, Greco, and Lee (2009) recently found that the right prefrontal cortex, parietal cortex and basal ganglia are significantly active during the performance of the TOL. Other activated brain regions include the dorsolateral prefrontal cortex, striatum, premotor cortex, supplementary motor area, and visuospatial system (van den Heuvel et al., 2003). Therefore, based on the improved TOL performance observed in our study, we provide evidence that the effect of acute exercise could be due to enhanced executive function through activity of the regulative system.

With respect to the dose-response relationship, the current study replicated and expanded upon the findings of previous studies (Chang & Etnier, 2009b). Using multiple resistance exercise intensities, Chang and Etnier (2009b) indicated that an inverted-U trend is present in tasks related to executive function (e.g., PASAT). In addition, the inverted-U trend is more noticeable with increasing task complexity, where the moderate intensity (70% 10-RM) condition shows the highest level of performance. In the current study, a similar U-shaped facilitation trend was observed for TOL performance; participants in both moderate intensity (40% and 70% 10-RM) conditions had better performance than those in the control and 100% 10-RM conditions. It has been argued that the processing involved in the PASAT and TOL tests may differ, given that PASAT involves active maintenance, divided attention, dual processing, and speed of digit and math retrieval, whereas the TOL involves more plan-related attentional allocation and mental flexibility. To complete the TOL, participants need to use several strategies to meet the final goal and subgoals, a process for which they may need lower arousal levels. Consistent with this idea, 40–70% 10-RM was found to yield the optimal performance.

Attentional allocation could be alternative explanation for the U-shaped relationship and the concept was recently supported by neuro-electronic indices. Hillman, Pontifex, and Themanson (2009) indicated that, following acute moderate intensity exercise, the P3 component showed a larger amplitude and shorter latency during conducting executive function task. Similarly, Kamijo et al. (2009) found that the moderate intensity condition showed the larger P3 amplitude and shorter P3 latency compared with other conditions in both young and old populations. Given that P3
amplitude and latency represent the attentional resource allocation and efficiency of information processing during the cognitive performance, these results suggest acute exercise might benefit executive function performance via these approaches, where moderate intensity has an optimal amount of resources.

Previous studies have demonstrated a beneficial effect of acute resistance exercise on executive function (Chang & Etnier, 2009a, 2009b), and the current study expands on this finding by focusing on a middle-aged population and by using different neuropsychological assessment methods. In contrast, Pontifex et al. (2009) examined two types of exercise modalities (aerobic and resistance exercise) on cognition and found different results from the current study. In their study, improved Sternberg working memory performance immediately after and 30 min after exercise cessation were found when compared with the baseline condition; while no differences were observed in the acute resistance exercise condition. That study implies that resistance exercise may exert a selective effect on cognitive ability, and the current study provides plausible results to support this hypothesis.

The biological mechanism whereby resistance exercise improves cognitive performance may be similar to that of aerobic exercise. Cotman and Berchtold (2002) state that the benefits of exercise could involve molecular changes in the brain itself. In this respect, neurotrophic factors (e.g., brain-derived neurotrophic factor, BDNF) and growth factors (e.g., nerve growth factor) have been extensively investigated (Cotman, Berchtold, & Christie, 2007), although most of this research has been performed using aerobic exercise and animal models. Recently, Yarrow, White, McCoy, and Borst (2010) were the first to demonstrate that both acute and chronic resistance exercise significantly elevate BDNF levels in humans, implying that resistance exercise may result in a similar biological effect as aerobic exercise.

Other research has examined whether vascular endothelial growth factor (VEGF), an angiogenic growth factor, provides an alternative link between resistance exercise and cognition. Prior, Yang, and Terjung (2004) suggest that, to meet the challenges of exercise and muscle contractions, the vascular system increases the diameter and wall thickness of existing vessels, a process termed angiogenesis. Vascular endothelial growth factor and its related factors serve crucial roles during angiogenesis, and more importantly, VEGF activation occurs in response to exercise. Recently, animal research has indicated that following both acute and chronic exercise, VEGF transcription is not only elicited in the muscle, lung, heart and liver but also in the hippocampus, implying that the beneficial cognitive effects of exercise could be mediated via VEGF (Tang, Xia, Wagner, & Breen, 2010).

Some limitations of the current study should be considered. First, we did not collect physical fitness data directly, although we used HR baseline as an indirect index where no significant difference was found for this metric. Recently, Stroth et al. (2009) examined the effects of acute exercise on executive control using both the Erikson flanker task and event-related potentials. Participants with high fitness levels are associated with increased executive preparation processing and improve in the efficiency of the executive control process. Conversely, none of these results have been observed in acute exercise intervention. Issues related to physical fitness are still being debated (Brisswalter, Collardeau, & Arcelin, 2002), and the current experimental design should be replicated, taking into consideration of these variables. Moreover, more females were recruited in the current study than males. Although gender effects have not been specifically examined in the
exercise-cognition relationship, data based on the assumption of gender equality should be interpreted with caution.

Several future research directions should be considered. Previous studies have been demonstrated the positive acute exercise effect on a variety of cognitive performances; however, research have been targeted college-aged population mainly. There is a continuing need for examining other populations including children, middle-, older-aged adults, and therefore, the effect of exercise on cognition across lifespan could be fully understand. In addition, many studies have recently used neuro-electric indices (Hillman, Pontifex, Raine, et al., 2009; Hillman, Pontifex, & Themanson, 2009; Kamijo et al., 2009; Themanson & Hillman, 2006) as metrics to investigate the underlying mechanisms affecting acute exercise and cognition. These findings provide deep insight into this relationship; however, no study has focused on resistance exercise. Moreover, molecular mechanisms, including VEGF, BDNF, and other types of growth factors, have been linked to the effects of exercise on cognitive performance (Cotman & Berchtold, 2002). Given that current research into the mechanisms underlying this link emphasizes aerobic exercise, further research regarding the role of other types of exercise should be pursued. Lastly, there is some controversy regarding the influence of the time delay effect. Some research indicates that the acute exercise effect lasts 30–52 min after exercise session cessation (Joyce et al., 2009; Themanson & Hillman, 2006) whereas other studies have failed to confirm this finding (Barella et al., 2010). This issue, therefore, warrants further investigation.

**Conclusions**

The present study demonstrates that an acute session of resistance exercise has a positive effect on executive function using the TOL as a performance indicator. Specifically, an U-shaped facilitation trend was found for the dose-response relationship between exercise intensity and planning performance related to correct moves and move scores, wherein middle-aged participants in the moderate intensity conditions showed more efficient performance than those in the control and high intensity conditions. Conversely, violation and planning speed-related scores showed only limited improvements following resistance exercise, implying that the effects of acute exercise on executive function are differentially sensitive. Although the current study supports the link between exercise and cognitive performance, examinations of exercise modalities and executive function tasks are in the initial stages. Future research into this area of study appears promising.

**Acknowledgments**

The present study was partially supported by research grant from National Science Council in Taiwan (NSC 98-2410-H-179-001).

**References**


*Manuscript submitted: May 2, 2011*

*Revision accepted: July 11, 2011*