Effect of Resistance-Exercise Training on Cognitive Function in Healthy Older Adults: A Review

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Several studies have demonstrated that exercise helps reduce or prevent cognitive deterioration among older adults, and recent studies have further examined the effects of resistance-exercise training on cognition. The purpose of this review was to examine the role of resistance-exercise training on cognition in healthy older adults. Specifically, it describes the definition, health benefits, and the design of resistance-exercise training. The authors also review the research related to resistance exercises and cognition and found that this exercise modality may enhance specific cognitive performances. Next, they examine the potential mechanisms underlying resistance exercise and cognitive enhancement. Finally, they consider potential therapeutics and recommendations for further research on resistance-exercise training and cognition in older adults.

Keywords: chronic exercise, resistance training, strength training, executive function, cognition

The older population has become the main growth segment in current society. According to the World Health Organization in 2000, 10%, or approximately 600 million people, were 60 years old or older, and globally, this number is expected to increase to 1.2 billion by 2025 and 1.9 billion by 2050 (Hutton, 2008). The older population is also growing significantly in the United States. In 2008, 38.9 million people age 65 years or older represented 12.8% of the U.S. population, which is an increase of 4.5 million over the previous decade (U.S. Department of Health and Human Services, 2010).

Aging is a dynamic and progressive process that results in deterioration of morphological, functional, hemodynamic, and psychological abilities and leads to reduced adaptive ability and quality of life, as well as increased morbidity (Roubenoff, 2000). Studies have shown that aging is negatively associated with volumes of
white matter, gray matter, hippocampus, and amygdala, as well as other brain regions including prefrontal, temporal, parietal, and occipital cortices (Raz & Rodrigue, 2006). Because these cortical and subcortical regions are involved in cognition, their deterioration is often accompanied by cognitive decline. Research has indicated that aging inhibits multiple cognitive functions, including information-processing speed, reasoning, attention, and multiple memory formations (Budson & Price, 2005; Park et al., 2002; Park & Reuter-Lorenz, 2009; Salthouse, 2003a, 2003b).

A considerable number of reviews have revealed that exercise, as a positive lifestyle factor, might alleviate or prevent these cognitive declines (Brisswalter, Collardeau, & Arcelin, 2002; Colcombe & Kramer, 2003; Etnier et al., 1997; McMorris & Graydon, 2000). Although most of them have primarily focused on aerobic exercise, a few studies have shifted their attention to emphasize the effects of other types of exercise modalities, particularly resistance exercise, on cognition and found positive effects. For example, a meta-analysis conducted by Colcombe and Kramer revealed that a long-term exercise program significantly enhanced cognition in the older population (effect size [ES] = 0.48); however, they also found that an exercise program with a combination of multiple exercise modalities (e.g., resistance exercise) enhanced cognition to a greater extent (ES = 0.59) than a program that only included aerobic exercise (ES = 0.41). Similar results were also found in older adults with cognitive impairments and dementia (ES = 0.57; Heyn, Abreu, & Ottenbacher, 2004). Liu-Ambrose and Donaldson’s (2009) commentary requested further examination of resistance exercise and cognition in older adults.

Recently, several reviews have focused on the effects of aerobic exercise on cognition, specifically focusing on neurocognition during aging (Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004), neural plasticity (Erickson & Kramer, 2009), epidemiology (Kramer, Erickson, & Colcombe, 2006), neurocognitive performance (Smith et al., 2010), and older adults with and without cognitive declines (van Uffelen, Chin A Paw, Hopman-Rock, & van Mechelen, 2008). Some reviews also focused on how a special exercise modality such as Tai Chi Chuan affects cognition in older adults (Chang, Nien, Tasi, & Etnier, 2010). However, to date, reviews have not focused on resistance exercise and cognition in healthy older adults. Therefore, the purpose of this article was to review the research regarding the effects of resistance exercise on cognition in older adults. Specifically, we briefly describe the definition and designs of resistance-exercise-training program, present reviews of literatures related to resistance exercise and cognition, and examine the potential mechanisms underlying resistance exercise and cognition. Finally, potential therapeutics and recommendations for further research are addressed.

**Resistance-Exercise Training**

**Definition and Health Benefits**

Resistance-exercise training, also known as resistance exercise, resistance training, or strength training, is a type of exercise that involves the voluntary activation of specific skeletal-muscle groups against external resistance (Winett & Carpinelli, 2001). Although resistance exercise was performed by only a few body builders in its early stages, it has become a popular form of exercise and is recommended by many health organizations, including the American College of Sports Medicine

Particularly for the older population, resistance exercise has been shown to increase muscle mass, strength, power, energy expenditure, and body-muscle composition (Haskell et al., 2007; Hunter, McCarthy, & Bamman, 2004). Such exercise has also been found to reduce the risk factors associated with age-related diseases including sarcopenia (Johnston, De Lisio, & Parise, 2008; Visvanathan & Chapman, 2010), coronary heart disease, hypertension, diabetes mellitus, metabolic syndrome, osteoporosis, osteoarthritis, and disability in the elderly (Hurley & Roth, 2000; Kraemer, Ratamess, & French, 2002). In addition to physical benefits, resistance-exercise training has been found to enhance positive well-being in the obese population (Levinger et al., 2009), as well as quality of life (Dibble, Hale, Marcus, Gerber, & LaStayo, 2009) and cognition (Cassilhas et al., 2007; Liu-Ambrose et al., 2008; Ozkaya et al., 2005) in the older population.

Design and Recommendation

Individualization is the primary concern for designing a proper resistance exercise to achieve maximal results. Kraemer and colleagues (ACSM, 2009; Kraemer, Adams, et al., 2002; Kraemer & Ratamess, 2004) have provided detailed descriptions with several components that should be considered before forming a resistance-exercise-training program, including muscle action, exercise selection, workout structure, exercise order, loading, volume, rest periods between sets, repetition velocity, training frequency, and progressive overload. The descriptions of these components were briefly addressed based on Kraemer and colleagues, and additional studies related to specific components were also presented (Rhea, Alvar, Burkett, & Ball, 2003; Simao, Farinatti, Polito, Maior, & Fleck, 2005; Simao, Farinatti, Polito, Viveiros, & Fleck, 2007).

For muscle action, concentric and eccentric actions play the primary role in the dynamic repetitions of resistance-exercise training, but additional isometric actions are recommended to maximize strength gain. With regard to exercise selection, both single-joint exercises such as leg extensions and leg curls, that focus on specific muscle groups, and multiple-joint exercises such as bench press, squat, or power clean, that target multiple muscle groups, should be considered. The workout structure involves total-body workouts, upper/lower body split workouts, and muscle-group split routines. General recommendations are chosen based on the training goals (e.g., strength, hypertrophy, power, muscle endurance). Simao and colleagues indicated that the exercise order is based on several principles, including larger muscle groups before small ones, multiple-joint exercise before single-joint exercise, less complex movement before basic ones (e.g., squat or bench press), higher intensity before lower intensity when training individual muscle groups, and rotating upper and lower body movements or opposing (agonist–antagonist relationship) muscle groups (Simao et al., 2005; Simao et al., 2007).

Loading is usually applied using the one-repetition-maximum (1RM) method. Rhea et al. (2003) indicated that untrained individuals who use 60% 1RM gain maximal results (ES = 2.5–3), whereas trained individuals gain maximal results using the 80% 1RM (ES = 1.5–2). Volume can be calculated by using either the
number of sets and repetitions during a training session (Kraemer & Ratamess, 2004) or the sum of the number of sets and repetitions, then multiple loading (kg; ACSM, 2009). One to six sets or more have been found to increase muscle strength. For example, Rhea et al. (2003) indicated that four sets per muscle group produced maximal gains in both trained and untrained individuals (ES = 1–2.5). In addition, the rest period between sets has been shown to affect metabolic and cardiovascular responses. At least 2–3 min is recommended for untrained, intermediate individuals and for advanced training, whereas 1–2 min may suffice for assistance exercises (exercises complementary to core exercises; ACSM, 2009). Repetition velocity involves dynamic, constant external resistance, as well as unintentional and intentional slow velocities. All slow-, moderate-, and fast-velocity repetitions have been shown to be positively associated with the training level of individuals (ACSM, 2009). Frequency is defined as the number of times per week the exercise is performed, and the recommended frequency is two or three, three or four, and four or five times/week for untrained, intermediate, and trained individuals, respectively. Finally, progressive overload can be found by increasing the load, repetition, velocity, and volume; shortening the rest periods; or any combination thereof (Kraemer & Ratamess, 2004).

When considering these components, the general exercise recommendation of ACSM guidelines for older adults is as follows:

**Type:** Multiple-joint exercises that affect more than one muscle group are the primary recommendation, whereas single-joint exercises of major muscle groups are recommended for additional exercise.

**Load:** Moderate intensity (60–70% 1RM).

**Volume (repetition and set):** One or more sets of 10–15 repetitions with a rest interval of 2–3 min.

**Frequency:** At least twice per week with at least 48 hr separation for the same muscle groups to increase improvements (ACSM, 2010).

Moreover, to further improve strength and hypertrophy in older adults, the recommendations of the ACSM position stand that rank in the A category of evidence (the highest evidence rank, where a large number of well-designed randomized controlled trials [RCT] reveal consistent findings) involve the following:

**Type:** both multiple- and single-joint exercises with either free weights or machines

**Load:** 60–80% 1RM

**Volume:** one to three sets per exercise with 8–12 repetitions

**Rest and velocity:** 1–3 min of rest with slow to moderate lifting velocity

**Frequency:** two or three times per week (ACSM, 2009)

Additional resistance-exercise training is recommended to focus on specific goals or expectations, such as muscle hypertrophy, muscle power, muscle endurance, and motor performance (ACSM, 2009); however, resistance-exercise-training recommendations for mental health and cognition are not yet established.
Reviews of the Literature Related to Resistance Exercise and Cognition

Several approaches were used to comprehensively search the potential research related to resistance-exercise training and cognition. Computer searches were conducted using multiple databases: MEDLINE, PubMed, PsycINFO, Educational Research in Completion (ERIC), and SPORTDiscus. Key terms in the search included resistance exercise, resistance training, strength exercise, strength training, muscle training, cognition, cognitive function, cognitive performance, executive function, and memory. Studies published in English from January 1996 to February 2010 were included. Additional criteria for inclusion were as follows: healthy adults without cognitive impairment or specific disease, adults with an average age older than 65 years, cognitive performance assessed by cognitive tasks or neuropsychological assessments, and studies that included control or comparable groups. Potential studies were also identified from the reference lists of studies and reviews found in the search.

Ten studies that examined the effects of resistance training on different aspects of cognition were identified: Three studies examined resistance exercise versus nonexercise (Kimura et al., 2010; Liu-Ambrose et al., 2008; Perrig-Chiello, Perrig, Ehrams, Staehelin, & Krings, 1998; see Table 1), four studies compared multiple exercise modalities (Brown, Liu-Ambrose, Tate, & Lord, 2009; Cancela Carral & Ayan Perez, 2007; Komulainen et al., 2010; Ozkaya et al., 2005; see Table 2), and three studies examined dose-response relationships (Cassilhas et al., 2007; Liu-Ambrose et al., 2010; Tsutsumi, Don, Zaichkowsky, & Delizonna, 1997; see Table 3).

Resistance Exercise Versus No Exercise

Perrig-Chiello et al. (1998) evaluated the effects of an 8-week resistance-training program on performance involving multiple cognitive tasks. The effects of short- and long-term exercise regimens were also examined. Older adults were randomly assigned into the resistance-training or control group. Cognitive performance was assessed using free-recall and recognition tests to measure memory and the digit-symbol test to measure cognitive speed, attention, coordination, and information-processing speed. The time course was assessed by evaluating performance 1 week before training, 1 week after training, and 1 year after training. Perrig-Chiello et al. indicated that although no between-groups differences were found, delayed free recall and immediate, as well as delayed, recognition, had significant improvements compared with baseline in resistance-training groups, while no effects were found in the control group. For long-term effects, resistance-training groups showed more improvement in free recall than the control group.

While targeting executive functions, a type of higher level cognition, Liu-Ambrose et al. (2008) examined the effects of an exercise program on specific types of cognition. They assigned older adults into either the Otago Exercise Program, a 6-month home-based program, or a control group using an RCT design. Cognitive performances, specifically set shifting, updating, and response inhibition, were
Table 1  Influences of Chronic Resistance Training on Cognition in Older Adults: Resistance Exercise Versus No Exercise

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>N (age), gender</th>
<th>Groups</th>
<th>Exercise</th>
<th>Design</th>
<th>Cognitive Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimura et al. (2010)</td>
<td>SB-RCT</td>
<td>171 (≥65 yr), both</td>
<td>ST (combination, see text), control (health education)</td>
<td>Rowing hip, abductor, knee extension, leg press</td>
<td>L = 3 mo, F = twice/week, I = 60% 1RM or 10RM, D = 1.5 hr, S = 2–3, R = 2 min, P = yes</td>
<td>Task-switching task Pre, post NS</td>
</tr>
<tr>
<td>Liu-Ambrose et al. (2008)</td>
<td>SB-RCT</td>
<td>74 (≥70 yr), both</td>
<td>Otago exercise program, control (guideline care)</td>
<td>Hip abductor, knee extensor, knee flexor, ankle plantar flexors, ankle dorsiflexors</td>
<td>L = 6 mo, F = at least twice/week, D = 30 min, I, S, R, P = WD</td>
<td>TMT-B, verbal digits-backward test, Stroop CW Pre, post Facilitation in Stroop CWa</td>
</tr>
</tbody>
</table>

Note. SB-RCT = single-blinded randomized controlled trial; ST = strength training; L = length; F = frequency; I = intensity; D = during; S = set; R = rest time; P = progression; NS = nonsignificant; WD = without description; TMT- B = The Trail Making Test Part B; Stroop CW = Stroop Color Word; Rand. = randomized.

aSignificant between-groups differences. bSignificant within-group differences.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>N (age), gender</th>
<th>Groups</th>
<th>Exercise</th>
<th>Design</th>
<th>Cognitive Tasks</th>
<th>Time</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown et al. (2009)</td>
<td>RCT</td>
<td>154 (62–95 yr), both</td>
<td>GE (resistance and balance), FR (flexibility and relaxation), control</td>
<td>Leg, truck, and arm movements</td>
<td>L = 6 mo, F = 2/wk, D = 60 min, I, S, R, P = WD</td>
<td>WAIS-R, TMT-B, Stroop CW, COWAT, WMS-R</td>
<td>Pre, post</td>
<td>Facilitation in WAIS-R*a</td>
</tr>
<tr>
<td>Cancela Carral and Ayan Perez (2007)</td>
<td>RCT</td>
<td>62 (M 68.4 yr), female</td>
<td>ST with aquatic exercise, callisthenic training with aquatic exercise</td>
<td>Vertical butterfly, double-arm curl, forward shoulder press, hip flexion, lever seated rear lateral raise, leg press, leg extension</td>
<td>L = 5 mo, F = 5 times/wk (include 3 times ST), I = 75% 1RM, D = ~45 min, S = 3, R = 5 min, P = yes</td>
<td>MMSE</td>
<td>Pre, post</td>
<td>Facilitation in MMSE*b</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>(N) (age, gender)</th>
<th>Groups</th>
<th>Exercise</th>
<th>Design</th>
<th>Cognitive Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Komulainen et al. (2010)</td>
<td>RCT</td>
<td>1335 (57–78 yr), both</td>
<td>AE, RE, diet, AE &amp; diet, RE &amp; diet, control</td>
<td>10–14 muscle groups</td>
<td>L = 2 yr, F = 2 (1,000–1,500 kcal/wk) or 3 (&gt;1,500 kcal/wk), I = 60% 1RM or 15RM, S = 2, D, R = WD, P = see context</td>
<td>Word-list memory test, word-list recall test, verbal-fluency test, modified Boston naming test, constructional praxis &amp; clock-drawing test, MMSE</td>
</tr>
<tr>
<td>Ozkaya et al. (2005)</td>
<td>RCT</td>
<td>36 (60–85 yr), both</td>
<td>ST, endurance training, control (sedentary)</td>
<td>Biceps curl, arm raise, abdominal crunch, hip extension, knee flexion, seated lower leg lift, chair squat</td>
<td>L = 9 wk, F = 3/wk, I = 60–80% 1RM, D = WD, S = 1 or 3, R = 2 min, P = yes</td>
<td>Auditory oddball task</td>
</tr>
</tbody>
</table>

**Note.** RCT = randomized controlled trial; GE = group-based exercise; FR = flexibility exercise and relaxation technique; L = length; F = frequency; D = during; I = intensity; S = set; R = rest time; P = progression; WD = without description; WAIS-R = Wechsler Adult Intelligence Scale-Revised; TMT-B = The Trail Making Test Part B; Stroop CW = Stroop Color Word; COWAT = Controlled Oral Word Association Test; WSM-R = Wechsler Memory Scale-Revised; ST = strength training; MMSE = Mini-Mental Status Examination; AE = aerobic exercise; RE = resistance exercise; imm. = immediate.

*Significant between-groups differences. *Significant within-group differences.

**Table 2 (continued)**
Table 3  Influences of Chronic Resistance Training on Cognition in Older Adults: Dose-Response Relationship

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>N (age), gender</th>
<th>Groups</th>
<th>Exercise</th>
<th>Design</th>
<th>Cognitive Tasks</th>
<th>Time</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassilhas et al.</td>
<td>Rand.</td>
<td>62 (65–75 yr), male</td>
<td>High int., moderate int., control (stretch)</td>
<td>Chest press, vertical traction, abdominal crunch, lower back, leg curl, leg press</td>
<td>L = 24 wk, F = 3 wk, I = 50% 1RM or 80% 1RM, D = 60 min, S = 2, R = 1 min 30 s, P = yes</td>
<td>W AIS III, Toulouse-Pieron’s concentration attention test, Rey-Osterrieth complex-figure test</td>
<td>Pre, post</td>
<td>Both exercise groups facilitate W AIS III, WSM-R, &amp; Rey-Osterrieth. High-int. group facilitates additional in Toulouse-Pieron.(^a)</td>
</tr>
<tr>
<td>Liu-Ambrose et al.</td>
<td>SB-RCT</td>
<td>155 (65–75 yr), female</td>
<td>Once/wk, twice/wk, control (balance and tone)</td>
<td>Biceps curls, triceps extension, seated rowing, latissimus dorsi pull-down, leg press, hamstring curls, calf raise</td>
<td>L = 1 yr, F = 1 wk or 2/ wk, I = 6RM or 8RM, D = 60 min, S = 2, R = WD, P = yes</td>
<td>Stroop, TMT-A &amp; -B, verbal digit span forward and backward test</td>
<td>Pre, 6 mo post, 12 mo post</td>
<td>Both exercise groups facilitate Stroop and reduce whole-brain volume.(^a)</td>
</tr>
<tr>
<td>Tsutsumi et al.</td>
<td>Rand.</td>
<td>45 (61–86 yr), both</td>
<td>High-int. ST, low-int. ST, control</td>
<td>Shoulder press, lateral pull-down, fly, triceps press-down, arm curl, back extension, seated row, abdominal flexion, bench press, leg extension, leg curl</td>
<td>L = 12 wk, F = 3 wk, I = 75–85% 1RM or 55–65% 1RM, D = WD, S = 2, R = 1–2 min, P = yes</td>
<td>Mental arithmetic, computerized mirror drawing task</td>
<td>Pre, post</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. Rand. = randomized; int. = intensity; L = length; F = frequency; I = intensity; D = during; S = set; R = rest time; P = progression; W AIS III = Wechsler Adult Intelligence Scale III; WSM-R = Wechsler Memory Scale-Revised; SB-RCT = single-blinded randomized controlled trial; WD = without description; Stroop = Stroop Test; TMT-A and B = The Trail Making Test Part A and Part B; ST = strength training; NS = nonsignificant.

\(^a\)Significant between-groups differences.
Chang et al. assessed using the Trail Making Test Part B (TMT-B), Verbal Digits-Backward Test, and Stroop Color-Word Test. The results showed that there was a between-groups difference in response inhibition, where the exercise group increased by 12.8%. In contrast, set shifting and updating were only minimally affected by resistance exercise compared with the control group. Because inhibition is highly associated with fall prevention (Verghese et al., 2002), Liu-Ambrose et al. (2008) suggested that the fall-prevention effects of the Otago Exercise Program would be attributable to improvements in response inhibition.

However, Kimura et al. (2010) failed to find positive effects of strength training on executive function measured by the task switch. They randomly assigned participants to either a strength-training (combination of conditioning, strengthening, and functional training phases) or health-education course/control group. The cognitive test was conducted before and after a 3-month exercise or health-education program. The results indicated no significant between-groups differences in response time or in accuracy. Kimura et al. speculated that this result might be due to an insufficiently long and intense resistance-training program, which was unable to elicit changes in IGF-1 levels, a potential mechanism underlying resistance exercise and cognition.

In sum, two of three studies revealed that resistance-exercise training benefits specific cognitive performances, where both between-groups differences (an exercise group compared with a control group) and within-group differences (a posttest compared with a pretest) were found (Liu-Ambrose et al., 2008; Perrig-Chiello et al., 1998). However, these two studies provided lower sample sizes, as well as insufficient descriptions of resistance-exercise design, compared with Kimura et al. (2010). In addition, although both Kimura et al. and Liu-Ambrose et al. (2008) applied a higher standard single-blinded RCT design, the results yielded notable differences. These mixed findings might have resulted from discrepancies among participant characteristics, exercise design, or cognitive tasks among these studies. Future research is obviously needed in view of these concerns.

Multiple Exercises Comparison

In addition to studies that compared resistance-exercise training and no exercise training, some studies compared effects of multiple types of exercise modalities on cognitive performance. Cancela Carral and Ayan Perez (2007) examined the effects of multiple high-load (frequency and intensity) exercises on older women. They randomly assigned participants to either a high-intensity strength training combined with aquatic exercise (Group 1) or callisthenic training (aerobic exercise, mobility, and flexibility) combined with aquatic exercise (Group 2). Cognitive tasks were measured using the Spanish version of the Mini-Mental State Examination and were assessed both pre- and postprogram. The results showed that both exercise groups showed enhanced cognitive ability compared with baseline, suggesting that the high-frequency and -intensity program was beneficial for cognitive function among older women.

Brown et al. (2009) examined the effects of different types of group-based exercise programs on multiple aspects of cognitive performance in older adults. They recruited older participants from eight retirement facilities and randomly assigned each one to either a resistance- and balance-training (GE) group, a flexibility- and relaxation-training (FR) group, or a control group. Cognitive performances were
assessed based on three types of functions including fluid intelligence (measured by the Wechsler Adult Intelligence Scale-Revised), executive function (measured by the TMT-B, the Stroop Color-Word Test, and the Controlled Oral Word Association Test), and multiple types of memory (visual, verbal, and working). Brown et al. found that the GE group had more benefits than the FR and control group in fluid intelligence, while both the GE and FR groups had improved mood compared with the control group.

One study used event-related potential (ERP) to examine the underlying differences in neuroelectronic activity between exercise modality and cognition in older adults. Ozkaya et al. (2005) randomly assigned older adults to an endurance-training group (70% HRR, 50 min/session), a strength-training group, or a control group. Cognitive performance was assessed using the auditory oddball task, which induced ERP components before, during, and after intervention. The results revealed that both training groups had a faster latency in N1, N2, and P2, as well as larger amplitude in N1P2, P2N2, and N2P3, than the control group. Because latency and amplitude represented the stimulus classification speed and level of attentional resource allocation (Hillman, Snook, & Jerome, 2003), these results suggest that exercise positively influenced the participants’ neuroelectric processes during cognitive performance. In addition, compared with endurance training, strength training produced a shorter latency for P2 and N2, as well as a larger amplitude for N1P2, P2N2, and N2P3, suggesting that strength training had a better effect than endurance training.

In contrast, Komulainen et al. (2010) failed to show the same positive effects on cognition in a long-term multiple-treatment study. Using the RCT design, they assigned 1,410 subjects into six groups: aerobic exercise, resistance exercise, diet, aerobic exercise plus diet, resistance exercise plus diet, and control. The intervention was a 2-year program for resistance exercise. Aerobic exercises were 150 min or 180 min/week with 55–65% VO2max. Primary outcome measures for exercises included a VO2max test and physical activity questionnaires that could be translated to metabolic equivalents. Measures used to evaluate cognitive functions included a word-list memory test for immediate memory; a word-list recall test, a word-list recognition test, and a delayed constructional praxis test for delayed memory; a verbal-fluency test and the modified Boston naming test for verbal performance; a constructional praxis test and a clock-drawing test for visual performance; and the Mini-Mental State Examination. The initial analysis found no differences in the 2-year change in VO2max or in cognitive performance; however, secondary analyses indicated that improved VO2max in the aerobic, resistance, diet, and combined aerobic and diet groups was positively associated with immediate memory. However, improvements in delayed memory and verbal performance were found in the diet and aerobic-exercise groups.

In sum, all four studies were conducted using an RCT design, and two of them proposed between-groups cognitive differences between resistance-exercise and control groups (Brown et al., 2009; Ozkaya et al., 2005), while one revealed within-group cognitive differences in the exercise group (Cancela Carral & Ayan Perez, 2007). With the largest sample size, although Komulainen et al. (2010) failed to support the between-groups cognitive differences during the first 2 years, resistance-exercise-induced VO2max was positively associated with immediate memory, reflecting the potential link between resistance exercise and cognition.
Dose-Response Relationship

Another research direction is investigation of the dose-response relationship between specific resistance-training components (e.g., intensity, duration, length) and cognition in older adults. Examining the dose-response relationship is beneficial for establishing exercise prescription for specific conditions.

Tsutsumi et al. (1997) examined the dose-response relationship between exercise intensity and neurocognitive function. Older adults were randomly assigned into a high-intensity resistance-training group, a low-intensity resistance-training group, or a control group. The high-intensity resistance-training group used resistance exercise of 75–85% 1RM with 8–12 repetitions, whereas the low-intensity group included exercises of 55–65% 1RM with 12–16 repetitions. Cognitive-task performance (mental arithmetic and a computerized mirror drawing task) were measured before and after the 12-week intervention. Both exercise groups showed enhanced muscle strength and mood, whereas VO2_{max} and cognitive performance did not change significantly, suggesting that resistance training using different intensities has limited influence on cognition.

However, some studies have reported contrasting results. Cassilhas et al. (2007) also studied the effect of resistance-training intensity on cognition. Using a similar experimental design, older participants were randomly assigned to a high-intensity (80% 1RM), moderate-intensity (50% 1RM), or control group for 24 weeks. Cognitive assessments included the Wechsler Adult Intelligence Scale III (WAIS III) for central, executive, and short-term memory; the Wechsler Memory Scale-Revised (WSM-R) for the visual modality of short-term memory; Toulouse-Pieron’s concentration attention test for attention; and the Rey-Osterrieth Complex Figure Test for long-term episodic memory. Cassilhas et al. found that both exercise groups showed significant improvements in Longest Digit Span Forward (WAIS III), Corsi’s Block-Tapping Backward and Similarities (WSM-R), and Rey-Osterrieth Complex Figure Test immediate recall compared with the control group, while no differences were found between exercise groups. The high-intensity group showed additional better improvement on the Toulouse-Pieron concentration test than the control group. Furthermore, plasma IGF-1 levels in both exercise groups were higher than levels in the control group, suggesting that both resistance exercise intensities benefited older adults, with IGF-1 being a potential biological mechanism.

Liu-Ambrose et al. (2010) further examined the dose-response relationship of exercise frequency on executive function in older women. The older participants were randomly assigned to a once-weekly resistance-training, twice-weekly resistance-training, or control group. Cognitive tasks included the Stroop Test to assess selective attention and response inhibition, the TMT-A and TMT-B to assess set shifting, and the Verbal Digit Span Forward and Backward Tests to assess working memory at baseline, 6 months, and 12 months. In addition, magnetic resonance imaging was used to assess whole-brain volume. Liu-Ambrose et al. (2010) found that both exercise groups showed enhanced Stroop Test performance, which increased by 12.6% and 10.9% in the once- and twice-weekly groups, respectively, compared with the control group. In addition, both exercise groups had less whole-brain volume than the control group. These results suggest that resistance exercise, even once per week for 12 months, affects brain structure, as well as cognitive function in terms of selective attention and conflict resolution in older women.
In sum, although Tsutsumi et al. (1997) failed to find resistance-exercise effects on cognition, both Cassilhas et al.’s (2007) and Liu-Ambrose et al.’s (2010) studies proved differently. Cassilhas et al. further indicated a dose-response relationship between exercise intensity and attention performance. The positive results might be warranted in these particular circumstances because Cassilhas et al. and Liu-Ambrose et al. used better design (single-blinded RCT in Liu-Ambrose et al.), larger sample sizes, or longer exercise duration than Tsutsumi et al. Since only a few studies have examined the dose-response relationship, additional research on the issue should be encouraged.

Potential Mechanism Linking Resistance Exercise and Cognition

Many molecular mechanisms have been proposed to link exercise and cognition, including insulin-like growth factor (IGF-I), brain-derived neurotrophic factor, fibroblast growth factor 2, and vascular endothelial growth factor (VEGF; Cotman & Berchtold, 2002; Kramer & Erickson, 2007). Among them, IGF-1 has been recognized as a candidate factor that specifically connects resistance-exercise training and cognition.

IGF-1 is one of the most important hormones for growth and development in humans (Sonntag, Ramsey, & Carter, 2005) and is associated with aging in the brain (Ramsey, Weiner, Moore, Carter, & Sonntag, 2004; Sonntag et al., 2000). Thornton, Ingram, and Sonntag (2000) indicated that IGF-1 replacement enhanced learning and memory in aged rats. The mechanism included IGF-1-mediated increases in neurogenesis, vascular density, glucose utilization, and regulation of N-methyl-D-aspartic acid receptors in the brain (Lichtenwalner et al., 2001; Sonntag et al., 2000).

IGF-1 was shown to prevent the loss of brain tissue and increase concentrations of BDNF (Cotman & Berchtold, 2002) and VEGF, a molecule related to vessel growth (Lopez-Lopez, LeRoith, & Torres-Aleman, 2004). BDNF is found in the central nervous system and functions in areas associated with cognitive processes, such as the prefrontal cortex, striatum, hippocampus, cortex, septum neurons, cerebellum, and motor neurons. In addition, studies have indicated that IGF-1 enhances synaptic plasticity and neuronal survival, which would, in turn, improve cognitive performance (Adlard, Perreau, & Cotman, 2005; Cotman & Berchtold, 2002; Vaynman, Ying, Yin, & Gomez-Pinilla, 2006).

In rodents, studies have found that circulating levels and brain uptake levels of IGF-1 were elevated with increased exercise (Carro, Trejo, Busiguina, & Torres-Aleman, 2001), and IGF-1 could mediate exercise-induced neurogenesis in the hippocampus (Trejo, Carro, & Torres-Aleman, 2001). These results linking IGF-1 and resistance exercise have been extended to humans. Borst et al. (2001) assigned participants to either of two resistance programs or a control group to examine the effects of different numbers of sets of resistance training on IGF-1 levels. The exercise programs included one or three sets, 3 days/week for 25 weeks. Results indicated that although the three-set group increased 1RM compared with the one-set and control groups, both the one- and three-set groups showed significant increases in IGF-1 levels. In addition, IGF-1 increased by 20% after the first 13 weeks, and the levels were maintained from 13 to 25 weeks. Resistance training’s
positive association with IGF-I has also been proposed by other studies (Adamo & Farrar, 2006; Hameed et al., 2004).

Alternatively, Cassilhas et al. (2007) indicated that blood viscosity, or resistance of blood to flow, might explain how resistance-exercise training enhances cognition, particularly in the older population. Studies have indicated that blood viscosity is negatively associated with cognitive performance, with lower blood viscosity reducing transportation of nutrients and oxygen to the central nervous system. Resistance exercise increased blood flow (Umpierre & Stein, 2007), which, in turn, was associated with cognitive performance (Cassilhas et al., 2007).

In addition to molecular and physiological mechanisms, Ozkaya et al. (2005) applied ERP to investigate the potential mechanism between strength training, endurance training, and cognitive neuroelectronic activity. They indicated that both exercises could positively influence ERP components reflecting stimulus-classification speed and levels of attentional resource allocation compared with control groups. In addition, strength training might have better effects than endurance training, where some ERP components reveal additional positive neuroelectronic activities (see the section on Multiple Exercises Comparison for detail).

**General Discussion and Future Direction**

The effects of resistance-exercise training on cognition have only recently been studied. Although studies have reported conflicting findings on the role of resistance-exercise training in preventing cognitive decline with age, many studies have demonstrated a beneficial effect of such training on specific cognitive measures. In comparing resistance-exercise training with other types of exercise training such as flexibility, tone, relaxation, calisthenics, and even endurance exercises (Brown et al., 2009; Cancela Carral & Ayan Perez, 2007; Ozkaya et al., 2005), some studies have shown that resistance training produces equivalent or increased specific cognitive performances. These beneficial effects were supported by both behavioral and neuroelectric cognitive functions (Ozkaya et al., 2005). However, it should be noted that although all the studies included in the current review applied an RCT design, studies of higher quality (e.g., single-blinded RCT, larger sample sizes, etc.) yielded inconsistent findings. In addition, some of these results were revealed only concerning within-group differences; we cannot know whether the improvements were based on resistance exercise per se or other confounders (e.g., learning or practice effects). Interpretation of the relationship between resistance exercise and cognition, therefore, should be approached cautiously.

Nonetheless, among these studies, we propose that designs including loads from 60% to 80% 1RM, approximately seven movements in two sets with 2 min rest between sets at least twice per week for 2–12 months (usually 6 months), might positively affect cognition in older adults. The efficiency of the design is also based on the dose-response studies; Cassilhas et al. (2007) indicated that compared with 50% 1RM, 80% 1RM was more beneficial for a variety of cognitive performances, although Liu-Ambrose et al. (2010) showed that resistance exercise once or twice a week for 12 months was beneficial.

Although Komulainen et al. (2010) found that increased VO$_2$max in resistance training was linked to immediate memory, some studies did not show that resistance-
exercise training affects cognition (Kimura et al., 2010; Komulainen et al., 2010; Tsutsumi et al., 1997). Differences in the intensity level and length of the interventions might help explain this ambiguity. According to Borst et al. (2001), 25 weeks of intervention with an initial intensity set at 70% 1RM for chest/leg and 60% 1RM for other movements that increased to 1.8–2.7 kg after adaptation would enhance IGF-1 levels. In contrast, Kimura et al. and Komulainen et al. only used 60% 1RM. In addition, although Tsutsumi et al. applied 55–85% 1RM, the intervention was short (12 weeks). Therefore, the intensity and length chosen by these studies might be insufficient to elicit an increase in IGF-1 levels and cognition.

Several possible directions need to be further addressed with respect to resistance-exercise training and cognition. First, many studies applied a combination of exercise routines, such as balance or aquatic exercises, in which the effect of resistance-exercise training alone on cognition could not be elucidated, and some studies that examined resistance exercise alone provided insufficient descriptions of their experimental design (Brown et al., 2009; Perrig-Chiello et al., 1998). Second, to establish the optimal exercise prescription for older adults, findings of the dose-response relationship need to be confirmed. Currently, only issues of intensity and frequency have been addressed; that is, length, progression, set, and volume have not been thoroughly examined. Unfortunately, inconsistent results have been found thus far. In addition, a dose-response study conducted by Liu-Ambrose et al. (2010) focused primarily on senior women. Because Colcombe and Kramer (2003) indicated that gender might be a potential modulator of exercise and cognition, the dose-response relationship between genders should be studied further.

Third, previous studies examined the effects of resistance exercise on cognition using a variety of cognitive tasks, and these tasks might explain the inconsistent findings between studies. Colcombe and Kramer (2003) indicated that long-term exercise intervention increased cognitive function, but disproportionately. Specifically, they proposed that chronic exercise is most effective at increasing executive functions, which are forms of high-level cognition, followed by controlled, spatial, and speed-related cognitive functions. However, we found inconsistent results on the effects of resistance-exercise training. For example, some studies found that resistance training increased scores on the Stroop Test, a type of executive-function task (Liu-Ambrose et al., 2008; Liu-Ambrose et al., 2010), but other groups have shown limited effects (Brown et al., 2009). In addition, studies have found that resistance exercise has minimal effects on other types of executive-function-related tasks, including the TMT-B, the digits backward test, the Controlled Oral Word Association Test, and verbal fluency (Brown et al., 2009; Komulainen et al., 2010; Liu-Ambrose et al., 2008). These results raise two questions: First, is the effect of aerobic exercise the same as that of resistance exercise on cognition? Second, are there any differences in the influence of exercise based on the types of cognitive tasks or executive-function-related tasks? To answer the first question, further studies comparing aerobic exercise and resistance exercise are needed. A recent meta-analysis by Smith et al. (2010) focused on the second question. In contrast to Colcombe and Kramer, Smith et al. found a similar, but modest, aerobic-exercise effect in various cognitive tasks—such as attention and processing speed ($g = 0.158$), executive functions ($g = 0.123$), and memory ($g = 0.128$)—suggesting that the effects of exercise on different types of cognition were similar. However, because a variety of tasks have been used to address the relationship between exercise and
cognition, it is difficult to compare findings. To address this concern, Etnier and Chang (2009) identified the most commonly reported executive-function tasks recognized in the neuropsychological field and recommended further research to apply these specific tasks, which have been commonly used to measure executive function. If this approach is taken, future comparisons between studies might be attainable.

Another direction is to determine the time course of resistance-exercise-training effects on cognitive function. For example, most studies that assessed cognitive performance were conducted before and after the intervention. Only Perrig-Chiello et al. (1998) examined both the short-term and long-term follow-up effects of resistance training, and they found a sustained effect 1 year after the intervention in the delayed-recall performance task. Further research addressing these issues is encouraged. Regarding quality of design, although most studies have applied an RCT design, only three were single-blinded. Results from insufficient RCT design might overestimate the effects and lower the cause–effect relationships. Therefore, quality of design should be considered for future studies. Furthermore, only Cassilhas et al. (2007) investigated the mechanisms and relationship between IGF-1 and blood viscosity and found that only IGF-1 played a role in cognition. Because IGF-I is associated with many neuronal factors (e.g., BDNF, VEGF, neurogenesis) and the effects of aerobic exercise on cognition have been examined, future research on the involvement of IGF-1, as well as other neuronal factors, is recommended.

Last but not least, studies related to exercise and cognitive functions can be categorized into chronic exercise and acute exercise (Tomporowski, 2003). Kesaniemi et al. (2001) suggested that both chronic and acute exercise should be equally valued, because frequent repetition of acute exercises might induce changes that are more lasting. In addition, the mechanisms, phenomena, theories, and clinical applications of the two forms of exercises might be different. Based on our search, relatively few studies have examined how acute exercise influences cognitive performance (Chang & Etnier, 2009a, 2009b; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009), and none have focused on the older population. However, some of these studies demonstrated benefits of acute resistance exercise on cognition in both younger and middle-aged adults (Chang & Etnier, 2009a, 2009b), suggesting that these types of exercise studies should be further directed to older adults.

**Conclusions**

Cognitive decline is one of the characteristics of aging for older adults. Extensive research has shown the positive effects of aerobic exercise on cognition in older adults, with a recent focus on resistance exercise. Our review seeks to reiterate that resistance-exercise training might be potentially strategic to facilitating cognitive functions in older adults with cognition intact, where some studies have found a positive effect of resistance-exercise training on specific cognitive performances in either resistance-exercise training alone or in combination with other exercise regimens and in examination of the dose-response relationships focusing on intensity and frequency of exercise. Specifically, we found that intervention designs in loads of 60–80% 1RM with approximately seven movements in two sets separated by 2 min of rest at least twice per week for 2–12 months (usually 6 months) could positively affect cognition, including information-processing speed, attention,
memory formation, and specific types of executive function. These benefits might be influenced by the biological mechanisms (e.g., IGF-1) induced by resistance-exercise training.

Further studies are needed to address the relationship between resistance exercise and cognition in terms of design of resistance-exercise-training regimens, dose-response relationships, types of cognition, time courses, quality of experimental design, mechanisms, and issues of acute resistance exercise. We therefore believe that additional research focusing on resistance-exercise training and cognition is necessary before making further claims along these lines.

References


