International Journal of Aquatic Research and Education

Volume 7 | Number 3 Article 9

8-1-2013

Physiological Effects of Aquatic Exercise on Cognitive Function in the Aging Population

Lori A. Sherlock
West Virginia University, lsherlock@hsc.wvu.edu

W. Guyton Hornsby, Jr.
West Virginia University

James Rye
West Virginia University

International Journal of Aquatic Research and Education, 2013, 7, 266-278

International Journal of
Aquatic Research and Education
www.IJARE-Journal.com
EDUCATIONAL/REVIEW

The Physiological Effects of Aquatic Exercise on Cognitive Function in the Aging Population

Lori A. Sherlock, W. Guyton Hornsby, Jr., and James Rye

Neurocognitive decline, including Alzheimer's disease and other forms of dementia, is considered to be the world's fastest growing disease (Alzheimer's Association, 2011). Due to this escalation, research focused on determining causes, accelerants, impeding factors, and preventative strategies has become a focus of interest within the field. One of the principal points of study is the role that exercise plays in the maintenance or fortification against neurocognitive decline. Though there is a robust library of research focused on the effects of land-based exercise on cognitive function, currently there is no research that discusses the impact of aquatic-based exercise on these parameters. This paper will examine the effects of land-based exercise on cognitive function while bridging these results to the aquatic environment.

The aging process is comprised of many regular changes that occur in a maturing population across a lifespan. Both physical and cognitive decrements have been noted with increasing age resulting in accumulative concern for quality of life, medical costs, and loss of independence. Connections to increasing age have been linked to cognitive decline after peaking during early adulthood (Hillman et al., 2009; Park & Reuter-Lorenz, 2009), and symptoms have been noted to begin rapidly accelerating after age 60 (Barnes et al., 2007). Adults age 85 and older are reported to have a rate of dementia of nearly 50% (Park & Reuter-Lorenz, 2009). This neurocognitive frailty is a serious concern for the aging population; it affects an individual's ability to age efficaciously and may be one of the largest threats to successful aging in our society (Park & Reuter-Lorenz, 2009).

Research on neurocognitive frailty associated with the aging process has focused on exercise as a means of maintaining or fortifying cognitive ability and executive function. Both acute and chronic physical activity have been linked to significant cognitive, as well as physical benefit (Denkinger, Nikolaus, Denkinger, & Lukas, 2012; Middleton, Barnes, Lui, & Yaffe, 2010). Though the current research body has distinguished this link utilizing primarily land-based exercise interventions, the aquatic environment may provide added stimulus to further enhance executive function via physiological mechanisms and environmental enrichment.

Lori Sherlock and W. Guyton Hornsby are with the Department of Exercise Physiology, and James Rye is with the Curriculum and Instruction/Literacy Studies Department, all at West Virginia University in Morgantown, WV.

Age-Related Changes in Brain Structure

Structural decline within the frontal, parietal, and temporal lobes of the brain resulting in decrements in cognitive processes begin after early adulthood (after age 30) according to some research (Raz & Rodrigue, 2006; Park & Reuter-Lorenz, 2009). Total brain volume is reduced by approximately 5% per decade after age 40 with the greatest size reduction being observed in the caudate, cerebellum, hippocampus, and prefrontal areas (Park & Reuter-Lorenz, 2009; Scahill et al., 2003). There has also been evidence for declining volume of gray and white matter in the older adult with particular decrements being noted in the frontal and parietal cortex occurring after the fifth decade of life (Park & Reuter-Lorenz, 2009; Raz & Rodrigue, 2006). Dopaminergic receptors and synaptic density have similarly been shown to be reduced in quantity with age (Park & Reuter-Lorenz, 2009) while neuronal shrinkage and dysmorphology, dendritic spine loss, and neuronal body loss have similarly been noted with the aging process (Myers, 2008). Due to these structural neuronal alterations, information processing becomes less efficient. Processing speed, working memory capacity, and attention can all be adversely affected (Park & Reuter-Lorenz, 2009). Other components of memory remain virtually untouched by the aging process including long-term memory and implicit memory (Park & Reuter-Lorenz, 2009).

Exercise and Brain Structures

Aerobic Exercise

Aerobic training has been noted to have both acute and chronic effects on various components of executive function (Liu-Ambrose et al., 2010; Baker et al., 2010; Barnes, Yaffe, Satariano, & Tager, 2003; Bielak, 2010; Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Davis et al., 2007; Davis et al., 2007; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008; Liu-Ambrose et al., 2008; Swardfager et al., 2010; Teixeira et al., 2012). Research supports the link between participation in chronic aerobic exercise and improvements in spatial learning, memory, cognitive capacity, selective and divided attention, working memory, cognitive flexibility, planning, inhibition, decision making, problem solving, cognitive speed, and overall cognitive function (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Baker et al., 2010; Barnes et al., 2003; Birren & Fisher, 1995; Budde et al., 2008; Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; Hillman et al., 2009; Hillman, Erickson, & Kramer, 2008; Hillman, Snook, & Jerome, 2003; Ke, Huang, Liang, & Hsieh-Li, 2011; Liu-Ambrose et al., 2010; Man, Tsang, & Hui-Chan, 2010; Scherder, Eggermont, Geuze, Vis, & Verkerke, 2010; Smith et al., 2010; Van der Borght, Havekes, Bos, Eggen, & Van der Zee, 2007; Teixeira et al., 2012; Yágüez, Shaw, Morris, & Matthews, 2011). Aerobic training has also been correlated with increased cerebral electrical activity and neurotransmitter secretion as well as reductions in neural apoptosis, increased growth factor modulation, increased vascularization, declines in brain volume loss, and decelerated memory loss (Asl, Sheikhzade, Torchi, Roshangar, & Khamnei, 2008; Baker et al., 2010; Berkman et al., 1993; Blumenthal & Madden, 1988; Burns et al., 2008; Chaddock et al., 2010; Chan et al., 2005; Clarkson-Smith & Hartley, 1989; Deeny et al., 2008;

DOI: 10.25035/ijare.07.03.09

Erickson et al., 2011; Erickson et al., 2009; Fabre et al., 2002; Flöel et al., 2010; Goekint et al., 2010; Hillman et al., 2009; Hillman et al., 2008; Ke et al., 2011; Kim et al., 2010; Klusmann et al., 2010; Komulainen et al., 2010; Komulainen et al., 2008; McAuley et al., 2011; Nation et al., 2011).

The effects of a single acute bout of aerobic exercise have also been studied. Findings support neuropsychological improvements including increased attention, processing speed, concentration, and overall cognitive function (Budde et al., 2008; Carles et al., 2007; Coles & Tomporowski, 2008; Goekint et al., 2010; Hillman et al., 2009; Hillman et al., 2008; Hillman et al., 2003; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009).

The acute and chronic effects of aerobic training are widely documented and provide some insight linking the effects of exercise with executive function. The overall outcome of exercise is enhanced immune condition of the brain and its structures that results in improved neural plasticity. Though the majority of the studies that have been performed exhibit positive results associated with participation in exercise or accrual of cardiovascular fitness, there are some studies that do not display any variations in executive function with the addition of physical activity. These studies may not provide supporting evidence that aerobic training results in positive modifications in cognitive processes; however, they likewise do not illustrate any decrements.

Anaerobic Exercise

Anaerobic exercise in the form of strength training or short, intense bouts of exercise has not been a primary focus of study in relation to executive function. There are a limited number of studies that have addressed the use of this modality for cognitive adaptations. The chronic anaerobic training literature has reported no significant effects on neurocognitive function with varied levels of intensity (Liu-Ambrose et al., 2010; Pontifex et al., 2009). Acute effects of anaerobic training (effects noted during or immediately following the training stimulus) have reported increased levels of brain-derived neurotrophic factor (BDNF), epinephrine, and norepinephrine. Acute effects also include increased speed and improved reaction time, as well as working memory span, response inhibition, improved recall, accuracy, and learning efficiency (Lachman, Neupert, Bertrand, and Jette, 2006; Liu-Ambrose et al., 2010; Pontifex et al., 2009).

Combined Training

According to a meta-analytic study conducted by Colcombe and Kramer (2003, p. 128), "participants in combined strength and aerobic training regimens improved to a reliably greater degree than those in aerobic training alone." This finding may be due to the physiological variations in stimuli resulting in a more diverse manifestation of cognitive improvements (Colcombe & Kramer, 2003). Improvement in fitness parameters including strength, range of motion, and VO_{2max} can be achieved with both resistance training as well as aerobic training (Farrell, 2011; Komulainen et al., 2010). Additionally, fitness improvement may be more achievable if individuals participate in multimodal forms of exercise such as resistance training with aerobic training, or sprinting with moderate aerobic training.

Exercise Intensity and Duration

Exercise intensity, the extent of the physiological disruption or stress of the physical activity being performed, is multifactorial and may play a role in altering executive function. Age, training status, gender, environmental conditions, and health status all affect both the perception of exercise intensity and actual, absolute exercise intensity as measured by energy expenditure or VO_2. Implications that specifications or personalization in intensity of exercise, or total energy expenditure may result in increased benefits for cognitive function have been suggested (Angevaren, Vanhees, Nooyens, Wendel-Vos, & Verschuren, 2010; Fabre et al., 2002; Flöel et al., 2010; Middleton et al., 2011). Overall, recommendations for moderate to intense exercise have been well supported for improvements in executive function (Erickson et al., 2011; Radák et al., 2010; Stroth, Hille, Spitzer, & Reinhardt, 2009; van Uffelen, Chinapaw, Hopman-Rock, & van Mechelen, 2009; Zlomanczuk et al., 2006).

Duration of exercise training, or the time spent participating in the exercise bout, is considered to be another integral factor in determining effectiveness of an exercise intervention on cognitive function. Some studies report findings to support that duration provided the greatest impact on cognitive function (Davis et al., 2008). A review of literature conducted by Denkinger et al. (2012) indicated that the gold standard for cognitive intervention via exercise is 30 min of physical activity performed 5 times per week. This standard corresponds to the recommendations issued by the American College of Sports Medicine (ACSM) for general cardiorespiratory health and wellness.

Exercise Environment

The environment in which an individual is immersed can play a major role in the maintenance and development of executive function (Bielak, 2010; Zec, 1995). An environment that provides participants a means of stimuli, known as an ‘enriched environment,’ positively influences neurologic processes to become more efficient (Bielak, 2010; Hultsch, Hertzog, Small, & Dixon, 1999; Zec, 1995). This stimulus could be obtained from exercise, cognitively challenging activities, or a complex environment. A complex environment can be described as an individual’s exposure to changing contextual variables or diverse stimuli that require the individual to make multiple, complex decisions that place demand on their cognitive skills. Adaptivity and plasticity of neural structures via cerebral blood flow, increasing numbers of neural synapses or synaptic organization, hippocampal neurogenesis, neuronal survival, or an upsurge in neurochemical availability are all possible physiological explanations for this phenomenon (Bielak, 2010; Blackmore, Golmohammadi, Large, Waters, & Rietze, 2009; Galvan & Jin, 2007; Galvan & Bredesen, 2007; Hillman et al., 2008). These adaptations are theorized to occur within an enriched environment due to the fluctuating environmental needs resulting in the necessity for the central nervous system to recognize and perceive varying sensory input then determine and create an appropriate motor response corresponding with proper sequencing, timing, and coordination necessary for the action (Binder, Storandt, & Birge, 1999; Hultsch et al., 1999). The key component essential for the complex environment to deliver is a necessity for engagement in cognitively demanding situations (Hultsch et al., 1999).

DOI: 10.25035/ijare.07.03.09

Potential Effects of the Aquatic Environment on Cognitive Function

The aquatic environment boasts of being one of the most malleable exercise environments available and can provide a variety of benefits to a range of populations. The physical properties of water modify many physiological aspects of human function and thus have a direct reaction on exercise physiology.

Density and Specific Gravity

In an aquatic setting, density of an individual's body in relation to the water's density (otherwise known as specific gravity) is very important for maintenance of body position as well as dynamic balance. Thus, density and specific gravity can provide new challenges to individuals exercising in the water. Because of individualistic nature of density, specific gravity, and body fat distribution, each person entering the water is confronted uniquely with modifying muscular contractions, somatic awareness and concentration to maintain appropriate exercising posture. This can be made easier for some by increasing grounding forces (the effect of gravity) via adding weights to an individual's ankles or allowing time for adjustment by working in more shallow water where gravity remains the dominating force over buoyancy. Consequently, the effects can be gradually progressed to allow for greater stimulus from the aquatic environment. This can add another dimension to exercise intended to promote executive function. As noted previously, adding coordination, concentration or other cognitively demanding variables to exercise can result in more positive outcomes on cognitive performance (Bielak, 2010; Binder et al., 1999; Blackmore et al., 2009; Galvan & Jin, 2007; Galvan & Bredesen, 2007; Hillman et al., 2008; Small et al., 2006; Stroth et al., 2009; Zec, 1995).

Buoyancy

As an individual enters the water and becomes immersed, water is displaced and a buoyant effect is experienced that counteracts the gravitational force. This feature of the aquatic environment provides an option for 'weightless' exercise and can offer assistance, resistance, or support. These attributes associated with buoyancy can allow for greater comfort and involvement when participating in exercise or be used to challenge the immersed body. Buoyancy, in relation to density and specific gravity, also can offset the body's equilibrium when immersed to provide a challenge for postural maintenance and locomotor control. The additional perturbation can increase the cognitive demands during the exercise intervention to provide for greater cognitive stimuli resulting in improvements in executive function.

Hydrostatic Pressure

Hydrostatic pressure is the pressure exuded upon a body immersed in water. The applied pressure provides support to the physiological systems by assisting blood return to the heart and lymphatic fluid redistribution throughout the body (Gulick, 2010; Mourot et al., 2010). The effect of hydrostatic pressure enhancing venous return to the heart is a major contributing factor to a net reduction in heart rate while immersed (Becker & Cole, 2011; Kruel et al., 2009). Veins and venous blood flow are highly affected by external pressure, including muscular compression and hydrostatic pressure; thus, immersion results in a net increase in central venous pressure leading to a greater return of blood to the heart that shifts the heart rate downward. The result of this blood shift is an increase in central volume, cardiac volume, mean stroke volume, and cardiac output leading to a more efficient cardiovascular system. Another result of the increased blood distribution is an increase in circulatory capacity, or greater availability of blood to shunt to the working tissues. Though circulatory impact of immersion has not been studied in the brain, it is accepted that muscular blood flow more than doubles with immersion (1.8 ml/min/100 g of tissue on land to 4.1 ml/min/100 g of tissue in neck-depth water) as does the metabolic waste removal capability of the circulatory system (increases seen were 225% above that of land metabolic waste removal; Balldin, Dahlback, & Lundgren, 1971). Hydrostatic pressure also supplies enough pressure around the thoracic cavity, via direct pressure and reallocation of blood into the chest cavity, to increase the work of respiration by 60% (Hong, Cerretelli, Cruz, & Rahn, 1969). In addition, hydrostatic pressure is theorized to provide a stimulation overload via skin sensory nerve endings including temperature, touch, and pressure receptors throughout the body to elicit a reduction in pain sensation (Günther, Mur, Kinigadner, & Miller, 1994).

All of these varying stimuli produce an aquatic environment that provides the body with novel stimuli that may further engage the cognitive processes to reduce cognitive dysfunction. Enhanced circulation may also prove to further augment cognitive maintenance or development. As stated previously, the literature supports that improvement in cerebral blood flow may produce positive structural modifications in cerebral tissue that promote improved executive function (Barnes et al., 2003; Bielak, 2010; Deeny et al., 2008; Lachman, et al., 2006; Man et al., 2010; Scherder et al., 2010; Small et al., 2006).

Viscosity

The viscosity, or relative thickness of a liquid, delivers a much higher resistance than that of air resulting in an increased amount of force required to elicit movement. Viscosity of water does not become a relative variable until movement is produced by a body or limb. The force needed to move a body, limb, or object through the water is highly related to the speed of movement being produced, the frontal surface area and shape of the object being moved through the water, and the amount of turbulent flow present in the water during the movement.

Due to the variability of contractile forces, muscular recruitment, and stimuli, neuromuscular recruitment patterns are altered highly in an aquatic setting (Colado, Triplett, Tella, Saucedo, & Abellan, 2009a; Colado, Tella, Triplett, & Gonzalez, 2009b; Colado, Tella, & Triplett, 2008; Triplett et al., 2009c). Theoretically, this could yield adaptation to cerebral function, hormonal interactions, or even neurogenesis by adding new, complex movement patterns into an individual's exercise prescription to develop a more enriched environment (Budde et al., 2008; Hultsch et al., 1999; Klusmann et al., 2010; Man et al., 2010; Stroth et al., 2009). It has also been noted that combined exercise training (resistance training paired with aerobic training) may improve to a greater degree than just using a single modality

DOI: 10.25035/ijare.07.03.09

(Colcombe & Kramer, 2003). The aquatic environment lends itself well to applying this theory as every movement produced is counteracted by the viscous force of water thus promoting resistance training while performing aerobic training.

Conclusions on the Aquatic Environment

Generally speaking, the greater the level of immersion, the greater the effect the aquatic environment will elicit on the immersed body. Many physiological effects are produced during immersion that could potentially affect executive function. The environment in and of itself affords various new stimuli to further develop the exercise session from mere exercise to exercise within a more enriched environment. The challenges that the physical attributes of the aquatic environment lend to individuals in the pool also drive the requirement for added concentration, variance of muscular contractions, and coordination while performing aquatic exercise. The buoyant support that the water provides may increase comfort during exercise for a variety of populations allowing them to enjoy the exercise experience more while promoting participation that can lead to longevity. Lastly, the increase in circulatory function that augments blood availability may potentially lead to increased cerebral circulation which has been definitively seen to promote neural structure maintenance and growth (Barnes et al., 2003; Bielak, 2010; Deeny et al., 2008; Lachman, et al., 2006; Man et al., 2010; Scherder et al., 2010; Small et al., 2006).

All of these aspects of participating in water exercise have the potential to promote, enhance, or even improve upon the effects of dry-land exercise on cognitive function. It is well accepted that land exercise promotes a multifaceted chain of reactions to stimulate positive alterations in executive function but these progressive results could be augmented by modifying the exercise medium. With the addition of immersing the body while performing exercise, the individual could potentially experience a heightened level of executive function adaptation prompted by greater environmental stimulation and improved circulation. In addition, adherence and continuation of exercise participation may also be superior. Studies support a higher level of both adherence and exercise continuation when the physical activity is performed in water (Bennell & Hinman, 2011; Munguía-Izquierdo & Legaz-Arrese, 2008; Kang, Ferrans, Kim, Kim, & Lee, 2007; Wang, Belza, Elaine, Whitney, & Bennett, 2007; Belza, Topolski, Kinne, Patrick, & Ramsey, 2002). This may be, in part, due to the sensation of security that the water provides, the reduction in pain stimulated by hydrostatic pressure, or the off-loading of the joints promoted by the upward force of buoyancy. Regardless of the reasons behind this finding, continuation of exercise is noted to be paramount for continued cognitive benefits (Barnes et al., 2007; Erickson et al., 2009; Weuve et al., 2004). Thus the water may be the ideal medium for promoting neural benefits and executive function for this sole reason.

Conclusions

The aging process has vast effects on executive function that result in diminished quality of life, increased medical costs, and loss of independence. Age-related changes in brain structure primarily occurring within the frontal, parietal, and temporal lobes beginning after the age of 30 have been distinguished as one of the primary causes related to age-related cognitive decline (Raz & Rodrigue, 2006; Park & Reuter-Lorenz, 2009). Fortunately, these neurophysiological alterations can be curtailed or even overturned with the inclusion of physical activity and accrual of fitness.

Exercise can acutely or chronically affect the somatic systems to provide alterations resulting in improvements in cognitive function. The varying physical properties of water may provide further opportunity for cognitive adaptation via utilizing both the physiological attributes (somatic stimulation and enhanced circulation) as well as the environmental qualities (support, resistance, and comfort) that the aquatic environment possess. Aquatic exercise may be the ideal mode and medium to enhance cognitive function in the aging population. Further research is needed to support or refute this hypothesis.

References

Alzheimer's Association (2011). Alzheimer's disease facts and figures. *Alzheimer's & Dementia, 7,* 208–244.

Angevaren, M., Aufdemkampe, G., Verhaar, H.J., Aleman, A., & Vanhees, L. (2008). Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. *Cochrane Database of Systematic Reviews, 3,* CD005381.

Angevaren, M., Vanhees, L., Nooyens, A.C., Wendel-Vos, C.G., & Verschuren, W.M. (2010). Physical activity and 5-year cognitive decline in the Doetinchem cohort study. *Annals of Epidemiology, 20,* 473–479. PubMed doi:10.1016/j.annepidem.2010.03.007

Asl, N.A., Sheikhzade, F., Torchi, M., Roshangar, L., & Khamnei, S. (2008). Long-term regular exercise promotes memory and learning in young but not in older rats. *Pathophysiology, 15,* 9–12. PubMed doi:10.1016/j.pathophys.2007.10.002

Baker, L. D., Frank, L. L., Foster-Schubert, K., Green, P. S., Wilkinson, C. W., McTiernan, A., Cholerton, B.A., Plymate, S.R., Fishel, M.A., Watson, G.S., Duncan, G.E., Mehta, P.D., Craft, S. (2010). Aerobic exercise improves cognition for older adults with glucose intolerance, a risk factor for Alzheimer's disease. *Journal ofAlzheimers Disease, 22,* 569-579.

Balldin, U.I., Dahlback, G.O., & Lundgren, C.E. (1971). Changes in vital capacity produced by oxygen breathing during immersion with the head above water. *Aerospace Medicine, 42,* 384–387. PubMed

Barnes, D.E., Cauley, J.A., Lui, L.Y., Fink, H.A., McCulloch, C., Stone, K.L., Yaffe, K. (2007). Women who maintain optimal cognitive function into old age. *Journal of the American Geriatrics Society, 55,* 259–264. PubMed doi:10.1111/j.1532-5415.2007.01040.x

Barnes, D.E., Yaffe, K., Satariano, W.A., & Tager, I.B. (2003). A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. *Journal of the American Geriatrics Society, 51,* 459–465. PubMed doi:10.1046/j.1532-5415.2003.51153.x

Becker, B.E., & Cole, A.J. (2011). *Comprehensive Aquatic Therapy* (3rd ed.). Pullman, WA: Washington State University Publishing.

Belza, B., Topolski, T., Kinne, S., Patrick, D.L., & Ramsey, S.D. (2002). Does adherence make a difference? Results from a community-based aquatic exercise program. *Nursing Research, 51,* 285–291. PubMed doi:10.1097/00006199-200209000-00003

Bennell, K.L., & Hinman, R.S. (2011). A review of the clinical evidence for exercise in osteoarthritis of the hip and knee. *Journal of Science and Medicine in Sport, 14,* 4–9. PubMed doi:10.1016/j.jsams.2010.08.002

Berkman, L.F., Seeman, T.E., Albert, M., Blazer, D., Kahn, R., Mohs, R., Finch, C., Schneider, E., Cotman, C., McClearn, G., Nesselroade, J., Featherman, D., Garmezy, N., McKann,

DOI: 10.25035/ijare.07.03.09

G., Brim, G., Prager, D., Rowe, J. (1993). High, usual and impaired functioning in community-dwelling older men and women: findings from the MacArthur Foundation Research Network on Successful Aging. *Journal of Clinical Epidemiology, 46,* 1129–1140. PubMed doi:10.1016/0895-4356(93)90112-E

Bielak, A.A. (2010). How can we not 'lose it' if we still don't understand how to 'use it'? Unanswered questions about the influence of activity participation on cognitive performance in older age–a mini-review. *Gerontology, 56,* 507–519. PubMed doi:10.1159/000264918

Binder, E.F., Storandt, M., & Birge, S.J. (1999). The relation between psychometric test performance and physical performance in older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 54,* M428–M432. PubMed doi:10.1093/gerona/54.8.M428

Birren, J.E., & Fisher, L.M. (1995). Aging and speed of behavior: possible consequences for psychological functioning. *Annual Review of Psychology, 46,* 329–353. PubMed doi:10.1146/annurev.ps.46.020195.001553

Blackmore, D.G., Golmohammadi, M.G., Large, B., Waters, M.J., & Rietze, R.L. (2009). Exercise increases neural stem cell number in a growth hormone-dependent manner, augmenting the regenerative response in aged mice. *Stem Cells (Dayton, Ohio), 27,* 2044–2052. PubMed doi:10.1002/stem.120

Blumenthal, J.A., & Madden, D.J. (1988). Effects of aerobic exercise training, age, and physical fitness on memory-search performance. *Psychology and Aging, 3,* 280–285. PubMed doi:10.1037/0882-7974.3.3.280

Budde, H., Voelcker-Rehage, C., Pietrabyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441,* 219–223. PubMed doi:10.1016/j.neulet.2008.06.024

Burns, J.M., Cronk, B.B., Anderson, H.S., Donnelly, J.E., Thomas, G.P., Harsha, A., Brooks, W.M., Swerdlow, R.H. (2008). Cardiorespiratory fitness and brain atrophy in early Alzheimer disease. *Neurology, 71,* 210–216. PubMed doi:10.1212/01.wnl.0000317094.86209.cb

Carles, S., Jr., Curnier, D., Pathak, A., Roncalli, J., Bousquet, M., Garcia, J.L., Galinier, M., Senard, J.M. (2007). Effects of short-term exercise and exercise training on cognitive function among patients with cardiac disease. *Journal of Cardiopulmonary Rehabilitation and Prevention, 27,* 395–399. PubMed

Chaddock, L., Erickson, K.I., Prakash, R.S., Kim, J.S., Voss, M.W., VanPatter, M., Pontifex, M.B., Raine, L.B., Konkel, A., Hillman, C.H., Cohen, N.J., Kramer, A.F. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research, 1358,* 172–183. PubMed doi:10.1016/j.brainres.2010.08.049

Chan, A.S., Ho, Y.C., Cheung, M.C., Albert, M.S., Chiu, H.F., & Lam, L.C. (2005). Association between mind-body and cardiovascular exercises and memory in older adults. *Journal of the American Geriatrics Society, 53,* 1754–1760. PubMed doi:10.1111/j.1532-5415.2005.53513.x

Clarkson-Smith, L., & Hartley, A.A. (1989). Relationships between physical exercise and cognitive abilities in older adults. *Psychology and Aging, 4,* 183–189. PubMed doi:10.1037/0882-7974.4.2.183

Colado, J.C., Tella, V., & Triplett, N.T. (2008). A method for monitoring intensity during aquatic resistance exercises. *Journal of Strength and Conditioning Research, 22,* 2045–2049. PubMed doi:10.1519/JSC.0b013e31817ae71f

Colado, J.C., Tella, V., Triplett, N.T., & Gonzalez, L.M. (2009). Effects of a short-term aquatic resistance program on strength and body composition in fit young men. *Journal of Strength and Conditioning Research, 23,* 549–559. PubMed doi:10.1519/JSC.0b013e31818eff5d

Colado, J.C., Triplett, N.T., Tella, V., Saucedo, P., & Abellan, J. (2009). Effects of aquatic resistance training on health and fitness in postmenopausal women. *European Journal of Applied Physiology, 106,* 113–122. PubMed doi:10.1007/s00421-009-0996-7

Colcombe, S., & Kramer, A.F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14,* 125–130. PubMed doi:10.1111/1467-9280.t01-1-01430

Coles, K., & Tomporowski, P.D. (2008). Effects of acute exercise on executive processing, short-term and long-term memory. *Journal of Sports Sciences, 26,* 333–344. PubMed doi:10.1080/02640410701591417

Davis, C.L., Tomporowski, P.D., Boyle, C.A., Waller, J.L., Miller, P.H., Naglieri, J.A., Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport, 78,* 510–519. PubMed

Davis, S.W., Dennis, N.A., Daselaar, S.M., Fleck, M.S., & Cabeza, R. (2008). Que PASA? The posterior-anterior shift in aging. *Cerebral Cortex, 18,* 1201–1209. PubMed doi:10.1093/cercor/bhm155

Deeny, S.P., Poeppel, D., Zimmerman, J.B., Roth, S.M., Brandauer, J., Witkowski, S., Hearn, J.W., Ludlow, A.T., Contreas-Vidal, J.L., Brandt, J., Hatfield, B.D. (2008). Exercise, APOE, and working memory: MEG and behavioral evidence for benefit of exercise in epsilon4 carriers. *Biological Psychology, 78,* 179–187. PubMed doi:10.1016/j.biopsycho.2008.02.007

Denkinger, M.D., Nikolaus, T., Denkinger, C., & Lukas, A. (2012). Physical activity for the prevention of cognitive decline: current evidence from observational and controlled studies. *European Journal of Geriatrics, 45,* 11–16. PubMed

Erickson, K.I., Prakash, R.S., Voss, M.W., Chaddock, L., Hu, L., Morris, K.S., White, S.M., Wojcicki, T.R., McAuley, E., Kramer, A.F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus, 19,* 1030–1039. PubMed doi:10.1002/hipo.20547

Erickson, K.I., Voss, M.W., Prakash, R.S., Basak, C., Szabo, A., Chaddock, L., Kim, J.S., Heo, S., Alves, H., White, S.M., Wojcicki, T.R., Mailey, E., Vieira, V.J., Martin, S.A., Pence, B.D., Woods, J.A., McAuley, E., Kramer, A.F. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 3017–3022. PubMed doi:10.1073/pnas.1015950108

Fabre, C., Chamari, K., Mucci, P., Masse-Biron, J., & Prefaut, C. (2002). Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *International Journal of Sports Medicine, 23,* 415–421. PubMed doi:10.1055/s-2002-33735

Farrell, P.M.J.V.C. (2011). *ACSM's Advanced Exercise Physiology* (2nd ed.). Philadelphia: Lippincott Williams & Wilkins.

Flöel, A., Ruscheweyh, R., Kruger, K., Willemer, C., Winter, B., Volker, K., Lohmann, H., Zitzmann, M., Mooren, F., Breitenstein, C., Knecht, S. (2010). Physical activity and memory functions: are neurotrophins and cerebral gray matter volume the missing link? *Neuroimage, 49,* 2756–2763. PubMed doi:10.1016/j.neuroimage.2009.10.043

Galvan, V., & Bredesen, D.E. (2007). Neurogenesis in the adult brain: implications for Alzheimer's disease. *CNS & Neurological Disorders - Drug Targets, 6,* 303–310. PubMed doi:10.2174/187152707783220938

Galvan, V., & Jin, K. (2007). Neurogenesis in the aging brain. *Clinical Interventions in Aging, 2,* 605–610. PubMed

Goekint, M., Roelands, B., De, P.K., Knaepen, K., Bos, I., & Meeusen, R. (2010). Does a period of detraining cause a decrease in serum brain-derived neurotrophic factor? *Neuroscience Letters, 486,* 146–149. PubMed doi:10.1016/j.neulet.2010.09.032

Gulick, D.T. (2010). Effects of Aquatic Intervention on the Cardiopulmonary System in the Geriatric Population. *Topics in Geriatric Rehabilitation, 26,* 93–103.

Günther, V., Mur, E., Kinigadner, U., & Miller, C. (1994). Fibromyalgia - the effect of relaxation and hydrogavanic bath therapy on the subjective pain experience. *Clinical Rheumatology, 13,* 573–578. PubMed doi:10.1007/BF02242996

Hillman, C.H., Erickson, K.I., & Kramer, A.F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews. Neuroscience, 9,* 58–65. PubMed doi:10.1038/nrn2298

Hillman, C.H., Pontifex, M.B., Raine, L.B., Castelli, D.M., Hall, E.E., & Kramer, A.F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159,* 1044–1054. PubMed doi:10.1016/j.neuroscience.2009.01.057

Hillman, C.H., Snook, E.M., & Jerome, G.J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology, 48,* 307–314. PubMed doi:10.1016/S0167-8760(03)00080-1

Hong, S.K., Cerretelli, P., Cruz, J.C., & Rahn, H. (1969). Mechanics of respiration during submersion in water. *Journal of Applied Physiology, 27,* 535–538. PubMed

Hultsch, D.F., Hertzog, C., Small, B.J., & Dixon, R.A. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychology and Aging, 14,* 245–263. PubMed doi:10.1037/0882-7974.14.2.245

Kang, H.S., Ferrans, C.E., Kim, M.J., Kim, J.I., & Lee, E.O. (2007). Aquatic exercise in older Korean women with arthritis: identifying barriers to and facilitators of long-term adherence. *Journal of Gerontological Nursing, 33,* 48–56. PubMed

Ke, H.C., Huang, H.J., Liang, K.C., & Hsieh-Li, H.M. (2011). Selective improvement of cognitive function in adult and aged APP/PS1 transgenic mice by continuous non-shock treadmill exercise. *Brain Research, 1403,* 1–11. PubMed doi:10.1016/j.brainres.2011.05.056

Kim, S.E., Ko, I.G., Kim, B.K., Shin, M.S., Cho, S., Kim, C.J., Kim, S.H., Baek, S.S., Lee, E.K., Jee, Y.S. (2010). Treadmill exercise prevents aging-induced failure of memory through an increase in neurogenesis and suppression of apoptosis in rat hippocampus. *Experimental Gerontology, 45,* 357–365. PubMed doi:10.1016/j.exger.2010.02.005

Klusmann, V., Evers, A., Schwarzer, R., Schlattmann, P., Reischies, F.M., Heuser, I., Dimeo, F.C. (2010). Complex mental and physical activity in older women and cognitive performance: a 6-month randomized controlled trial. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 65A,* 680–688. PubMed doi:10.1093/gerona/glq053

Komulainen, P., Kivipelto, M., Lakka, T., Savonen, K., Hassinen, M., & Rauramaa, R. (2010). Exercise, fitness and cognition - a randomised controlled trial in older individuals: the DR's EXTRA study. *European Geriatric Medicine, 1,* 266–272. doi:10.1016/j.eurger.2010.08.001

Komulainen, P., Pedersen, M., Hanninen, T., Bruunsgaard, H., Lakka, T.A., Kivipelto, M., Hassinen, M., Rauramaa, T.H., Pedersen, B.K., Rauramaa, R. (2008). BDNF is a novel marker of cognitive function in ageing women: the DR's EXTRA Study. *Neurobiology of Learning and Memory, 90,* 596–603. PubMed doi:10.1016/j.nlm.2008.07.014

Kruel, L.F.M., Peyre-Tartaruga, L.A., Alberton, C.L., Muller, F.G., & Petkowizc, R. (2009). Effects of Hydrostatic Weight on Heart Rate During Water Immersion. *International Journal of Aquatic Research and Education, 3,* 178–185.

Lachman, M.E., Neupert, S.D., Bertrand, R., & Jette, A.M. (2006). The Effects of Strength Training on Memory in Older Adults. *Journal of Aging and Physical Activity, 14,* 59–73. PubMed

Liu-Ambrose, T., Donaldson, M.G., Ahamed, Y., Graf, P., Cook, W.L., Close, J., ... (2008). Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. *Journal of the American Geriatrics Society, 56,* 1821–1830. PubMed doi:10.1111/j.1532-5415.2008.01931.x

Liu-Ambrose, T., Nagamatsu, L.S., Graf, P., Beattie, B.L., Ashe, M.C., & Handy, T.C., Lord, S.R., Khan, K.M. (2010). Resistance training and executive functions: a 12-month randomized controlled trial. *Archives of Internal Medicine, 170,* 170–178. PubMed doi:10.1001/archinternmed.2009.494

Man, D.W., Tsang, W.W., & Hui-Chan, C.W. (2010). Do older t'ai chi practitioners have better attention and memory function? *Journal of Alternative and Complementary Medicine (New York, N.Y.), 16,* 1259–1264. PubMed doi:10.1089/acm.2009.0462

McAuley, E., Szabo, A.N., Mailey, E.L., Erickson, K.I., Voss, M., White, S.M., Wojcicki, T.R., Gothe, N., Olson, E.A., Mullen, S.P., Kramer, A.F. (2011). Non-Exercise Estimated Cardiorespiratory Fitness: Associations with Brain Structure, Cognition, and Memory Complaints in Older Adults. *Mental Health and Physical Activity, 4,* 5–11. PubMed doi:10.1016/j.mhpa.2011.01.001

Middleton, L.E., Barnes, D.E., Lui, L.Y., & Yaffe, K. (2010). Physical activity over the life course and its association with cognitive performance and impairment in old age. *Journal of the American Geriatric Society, 58,* 1322–1326. PubMed doi:10.1111/j.1532-5415.2010.02903.x

Middleton, L.E., Manini, T.M., Simonsick, E.M., Harris, T.B., Barnes, D.E., Tylavsky, F., Brach, J.S., Everhart, J.E., Yaffe, K. (2011). Activity energy expenditure and incident cognitive impairment in older adults. *Archives of Internal Medicine, 171,* 1251–1257. PubMed doi:10.1001/archinternmed.2011.277

Mourot, L., Teffaha, D., Bouhaddi, M., Ounissi, F., Vernochet, P., Dugue, B., Regnard, J., Monpere, C. (2010). Exercise rehabilitation restores physiological cardiovascular responses to short-term head-out water immersion in patients with chronic heart failure. *Journal of Cardiopulmonary Rehabilitation and Prevention, 30,* 22–27. PubMed

Munguía-Izquierdo, D., & Legaz-Arrese, A. (2008). Assessment of the effects of aquatic therapy on global symptomatology in patients with fibromyalgia syndrome: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 89,* 2250–2257. PubMed doi:10.1016/j.apmr.2008.03.026

Myers, J.S. (2008). Factors associated with changing cognitive function in older adults: implications for nursing rehabilitation. *Rehabilitation Nursing, 33,* 117–123. PubMed doi:10.1002/j.2048-7940.2008.tb00215.x

Nation, D.A., Hong, S., Jak, A.J., Delano-Wood, L., Mills, P.J., Bondi, M.W., Dimsdale, J.E. (2011). Stress, exercise, and Alzheimer's disease: a neurovascular pathway. *Medical Hypotheses, 76,* 847–854. PubMed doi:10.1016/j.mehy.2011.02.034

Park, D.C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annual Review of Psychology, 60,* 173–196. PubMed doi:10.1146/annurev.psych.59.103006.093656

Pontifex, M.B., Hillman, C.H., Fernhall, B., Thompson, K.M., & Valentini, T.A. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine and Science in Sports and Exercise, 41,* 927–934. PubMed doi:10.1249/MSS.0b013e3181907d69

Radák, Z., Hart, N., Sarga, L., Koltai, E., Atalay, M., Ohno, H., Boldogh, I. (2010). Exercise plays a preventive role against Alzheimer's disease. *Journal of Alzheimer's Disease, 20,* 777–783. PubMed

Raz, N., & Rodrigue, K.M. (2006). Differential aging of the brain: patterns, cognitive correlates and modifiers. *Neuroscience and Biobehavioral Reviews, 30,* 730–748. PubMed doi:10.1016/j.neubiorev.2006.07.001

Scahill, R.I., Frost, C., Jenkins, R., Whitwell, J.L., Rossor, M.N., & Fox, N.C. (2003). A longitudinal study of brain volume changes in normal aging using serial registered magnetic resonance imaging. *Archives of Neurology, 60,* 989–994. PubMed doi:10.1001/archneur.60.7.989

Scherder, E.J., Eggermont, L.H., Geuze, R.H., Vis, J., & Verkerke, G.J. (2010). Quadriceps strength and executive functions in older women. *American Journal of Physical Medicine & Rehabilitation, 89,* 458–463. PubMed doi:10.1097/PHM.0b013e3181d3e9f6

Small, G.W., Silverman, D.H., Siddarth, P., Ercoli, L.M., Miller, K.J., Lavretsky, H., Wright, B.C., Bookheimer, S.Y., Barrio, J.R., Phelps, M.E. (2006). Effects of a 14-day healthy longevity lifestyle program on cognition and brain function. *American Journal of Geriatric Psychology, 14,* 538–545. PubMed doi:10.1097/01.JGP.0000219279.72210.ca

Smith, P.J., Blumenthal, J.A., Hoffman, B.M., Cooper, H., Strauman, T.A., Welsh-Bohmer, K., Browndyke, J.N., Sherwood, A. (2010). Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosomatic Medicine, 72,* 239–252. PubMed doi:10.1097/PSY.0b013e3181d14633

Stroth, S., Hille, K., Spitzer, M., & Reinhardt, R. (2009). Aerobic endurance exercise benefits memory and affect in young adults. *Neuropsychological Rehabilitation, 19,* 223–243. PubMed doi:10.1080/09602010802091183

Swardfager, W., Herrmann, N., Marzolini, S., Saleem, M., Kiss, A., Shammi, P., Oh, P.I., Lancotot, K.L. (2010). Cardiopulmonary fitness is associated with cognitive performance in patients with coronary artery disease. *Journal of the American Geriatrics Society, 58,* 1519–1525. PubMed doi:10.1111/j.1532-5415.2010.02966.x

Teixeira, C.V., Gobbi, L.T., Corazza, D.I., Stella, F., Costa, J.L., & Gobbi, S. (2012). Non-pharmacological interventions on cognitive functions in older people with mild cognitive impairment (MCI). *Archives of Gerontology and Geriatrics, 54,* 175–180. PubMed doi:10.1016/j.archger.2011.02.014

Triplett, N.T., Colado, J.C., Benavent, J., Alakhdar, Y., Madera, J., Gonzalez, L.M., Tella, V. (2009). Concentric and impact forces of single-leg jumps in an aquatic environment versus on land. *Medicine and Science in Sports and Exercise, 41,* 1790–1796. PubMed doi:10.1249/MSS.0b013e3181a252b7

van der Borght, K., Havekes, R., Bos, T., Eggen, B.J., & van der Zee, E.A. (2007). Exercise improves memory acquisition and retrieval in the Y-maze task: relationship with hippocampal neurogenesis. *Behavioral Neuroscience, 121,* 324–334. PubMed doi:10.1037/0735-7044.121.2.324

van Uffelen, J.G., Chinapaw, M.J., Hopman-Rock, M., & van Mechelen, W. (2009). Feasibility and effectiveness of a walking program for community-dwelling older adults with mild cognitive impairment. *Journal of Aging and Physical Activity, 17,* 398–415. PubMed

Wang, T.J., Belza, B., Elaine, T.F., Whitney, J.D., & Bennett, K. (2007). Effects of aquatic exercise on flexibility, strength and aerobic fitness in adults with osteoarthritis of the hip or knee. *Journal of Advanced Nursing, 57,* 141–152. PubMed doi:10.1111/j.1365-2648.2006.04102.x

Weuve, J., Kang, J.H., Manson, J.E., Breteler, M.M., Ware, J.H., & Grodstein, F. (2004). Physical activity, including walking, and cognitive function in older women. *Journal of the American Medical Association, 292,* 1454–1461. PubMed doi:10.1001/jama.292.12.1454

Yágüez, L., Shaw, K.N., Morris, R., & Matthews, D. (2011). The effects on cognitive functions of a movement-based intervention in patients with Alzheimer's type dementia: a pilot study. *International Journal of Geriatric Psychiatry, 26,* 173–181. PubMed doi:10.1002/gps.2510

Zec, R.F. (1995). The neuropsychology of aging. *Experimental Gerentology, 30,* 431–442. PubMed doi:10.1016/0531-5565(94)00066-C

Zlomanczuk, P., Milczarek, B., Dmitruk, K., Sikorski, W., Adamczyk, W., Zegarski, T., Tafil-Klawe, M., Chesy, G., Klawe, J.J., Radowski, A. (2006). Improvement in the face/name association performance after three months of physical training in elderly women. *Journal of Physiological and Pharmacology, 57 Supplement 4,* 417–424.