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Short Review

The Effects of Aquatic Exercise on Cognitive Function: Systematic Review

Paul D. Loprinzi *

Exercise & Memory Laboratory, Department of Health, Exercise Science and Recreation Management, The University of Mississippi, University, MS 38677, USA; E-Mail: pdloprin@olemiss.edu

* **Correspondence:** Paul D. Loprinzi; E-Mail: pdloprin@olemiss.edu

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Abstract

The objective of this brief systematic review was to examine the effects of aquatic exercise on cognitive function. Studies were identified using electronic databases, including PubMed, PsychInfo, Sports Discus and Google Scholar. In total, 13 articles met the inclusionary criteria. Among the 13 studies, all 13 demonstrated beneficial cognitive effects from exercise. This included chronic aquatic exercise-induced improvements in global cognition, executive function, attention, learning and memory, cognitively-related biomarkers (e.g., BDNF) and cerebral oxygenation. For the two acute aquatic studies, listening errors, via an auditory vigilance task, was reduced when participants were emerged in chest-deep water, when compared to on land. These beneficial effects appear to occur across multiple populations, including children, adolescents, young adults and older adults with various conditions, such as Multiple Sclerosis, Alzheimer's disease, and fibromyalgia.

Keywords

Cognition; exercise; psychological; water-based

1. Introduction

Accumulating research demonstrates that both acute and chronic exercise have protective and therapeutic effects on cognitive function [1-4]. These evaluated exercise modalities often include land-based walking, jogging and/or cycling activities. Less research, however, has evaluated the extent to which aquatic-based exercise may improve and/or preserve cognitive function [5-6]. This is a notable area of interest for several reasons. First, this provides individuals with an alternative modality to exercise. Secondly, aquatic exercise is less weight-bearing than traditional land-based exercise, and thus, for co-morbid and elderly populations, this may be an attractive alternative to allow for engagement in safe, health-enhancing exercise. The purpose of the present study, written as a brief report, was to systematically evaluate the literature to evaluate the extent to which aquatic exercise is associated with cognitive function. To my knowledge, no such systematic review exits.

2. Materials and Methods

Studies were identified using electronic databases, including PubMed, PsychInfo, Sports Discus and Google Scholar. Articles were retrieved up to January 3, 2019 (no restriction was placed on how far back the study was published). The search terms, including their combinations, were: exercise, physical activity, aquatic, aqua, water, water-based, swimming, cognition, cognitive function, memory, and executive function.

To be eligible for inclusion in this review, studies had to be published in English and among humans; employ a cross-sectional, prospective or experimental design; include a measure of aquatic or water-based physical activity/exercise as the independent variable; and the outcome variable could be any neural, cognitively-related biomarker, or cognitive outcome measure. The computerized searches include 5,123 articles. In total, 13 articles met the above-stated criteria.

Records were managed via an extraction table that included study parameters of author, sample characteristics, study design, exercise protocol, outcome variable (cognition), and main findings. Each evaluated article that met the study criteria was read in its entirety, with these study parameters retrieved from each article.

3. Results

Table 1 displays the extraction table for the 13 studies. Among the 13 studies, 12 were experimental studies, whereas one was a case study [12]. Among the 12 experimental studies, 9 were conducted among middle-age to older adults, with 2 occurring among children/adolescents [7-8] and 1 among young adults [9]. Samples included healthy individuals, as well as those with intellectual disabilities [8], ADHD (attention deficit hyperactive disorder) [7], fibromyalgia [10-11], mild cognitive impairment [9], Alzheimer's disease [12], and multiple sclerosis [13].

The chronic aquatic exercise programs ranged from 7 days to 6 months, whereas several studies employed a single bout of aquatic exercise [9, 14]. Most of the aquatic exercise programs focused on aquatic exercise alone, whereas some evaluated it in combination with cranial electrotherapy stimulation [8], cognitive training [15-16], and land-based exercise training [17]. The cognitive outcomes varied, including global measures of cognition (e.g., MMSE; Mini-Mental State Exam), executive function, attention, learning and memory, language fluency, cognitive communication, cerebral oxygenation, and biomarkers (e.g., BDNF (brain-derived neurotrophic factor), VEGF (vascular endothelial growth factor), IGF-1 (insulin-like growth factor-1)) of cognitive function. Among the 13 studies, all 13 demonstrated beneficial cognitive effects from exercise. This included chronic aquatic exercise-induced improvements in global cognition, executive function, attention, learning and memory, cognitively-related biomarkers (e.g., BDNF) and cerebral oxygenation. For the two acute aquatic studies, listening errors, via an auditory vigilance task, was reduced when participants were emerged in chest-deep water, when compared to on land.

4. Discussion

The motivation for the present paper was a result of: 1) prior work demonstrating beneficial effects of exercise on cognitive function [1-4], 2) emerging work demonstrating beneficial effects of aquatic exercise on psychological well-being [18-19], and 3) the implications (e.g., feasibility, less weight-bearing) of aquatic exercise for health promotion purposes. The main finding of the present review was that, chronic aquatic exercise training appears to be effective in enhancing various biomarkers and cognitive outcomes. Further, short-term immersion in chest-deep water may also enhance cognition.

With regard to short-term immersion in chest-deep water, and as discussed elsewhere [14], water immersion may improve cerebral blood flow. Hydrostatic pressure may stimulate mechanoreceptors whose impulses may produce presynaptic inhibition or excitation of interneuron pathways. Further, partial aquatic immersion may also increase parasympathetic drive via a baroreflex from increased central blood volume and stroke volume.

Regarding chronic aquatic exercise, beneficial effects on cognition may arise from the acute benefits of water immersion as well as from enhancement effects from chronic engagement in exercise. Regarding the latter, and as discussed elsewhere [20-35], chronic exercise may have broad effects on cognition via alterations in angiogenesis, gliogenesis, and neurogenesis. Further, chronic exercise-induced enhancement of cardiorespiratory fitness may also play an important role in improving cognitive function [36].

In conclusion, this brief systematic review highlights the beneficial effects of acute water immersion and chronic aquatic exercise engagement in subserving cognitive function. These beneficial effects appear to occur across multiple populations, including children, adolescents, young adults and older adults with various conditions, such as Multiple Sclerosis, Alzheimer’s disease, and fibromyalgia. Additional work is needed that carefully compares chest deep water immersion vs. aquatic exercise, in an effort to determine whether it is water immersion or aquatic exercise that is driving the observed cognitive enhancement effects.

Table 1 Extraction table of the evaluated human studies.

Study	Subjects	Study Design	Exercise Protocol	Outcome Measure	Findings
Carral et al. (2007) [17]	62 community-dwelling women older than 65 yrs	Experimental; between-subject	Combined program of aquatic exercise plus high-intensity strength training (group 1) or plus calisthenics training (group 2). Intervention occurred 5 days a week for 5 months. Aquatic sessions last 45 mins and was progressive over 4 microcycles. Strength training involved 75% of 1 RM in 3 sets of 10 reps. Calisthenic training was progressive and lasted 45 minutes, and included 20 min of warm up exercise followed by 15 min of main exercises.	MMSE; assessment of cognitive orientation, memory and attention.	Both groups improved their overall MMSE score (P<0.05). Group 1 pre and post scores: 24.3 and 27.0 (t=-2.41, P=0.03). Group 2 pre and post scores: 22.1 and 27.1 (t=-2.87, P=0.02).
Munguia-Iqzuierdo et al. (2007) [11]	60 middle-aged women with fibromyalgia	Experimental; between-subject	16-weeks (3 sessions per week) of aquatic exercise. Each session included 10 min of warm up, then 10-20 min of strength exercises using aquatic materials, then 20-30 min of aerobic exercises at 50-80% of max heart rate, and then a 10 min cool down.	Paced Auditory Serial Addition Task, Repetition of Digits and Reversal of Digits, Trail Making, Controlled Oral Word Association test, RAVLT.	Aquatic exercise improved cognitive function for all cognitive outcome assessments (P<0.01).
Munguia-Iqzuierdo et al. (2008) [10]	60 middle-aged women with fibromyalgia	Experimental; between-subject	16-weeks of exercise in chest-high pool. Trained for 3 times per week. Each session included 10 min of warm up, 10-20 min of strength exercises, and 20-30 min of aerobic exercises at 50-80% of max heart rate.	Paced Auditory Serial Addition Task (PASAT)	Aquatic exercise improved cognitive function on the PASAT task. There was a greater change in PASAT in the exercise (6.7) vs. control group (1.2) (P=0.004) over the 16-week period.
Chang et al. (2014) [7]	30 children with ADHD	Experimental; between-subject	8-week aquatic exercise intervention (twice a week, 90 min per session). Each session included a 5-min warm-up, 40-min of moderate-intensity water aerobic exercise, 40-min of perceptual-motor water exercise, and a 5-min cool-down.	Go/NoGo task	Aquatic exercise increased NoGo accuracy associated with the Go/NoGo task. Group x time interaction, F=8.30, P=0.001).

Lee et al. (2014) [8]	15 adolescent males with intellectual disabilities	Experimental; between-subject	12-week intervention involving either control, aquatic exercise, or aquatic exercise plus cranial electrotherapy stimulation (Ex+CES). The aquatic program comprised of 10 min of preparation exercise, 30 min of main exercise and 10 min of cool-down exercise. Sessions occurred three times per week.	BDNF, IGF-1, VEGF, oral language test, written language test	Global cognitive function increased in the exercise and Ex+CES groups (Group x Time interaction, F=3.57). BDNF (Group x Time interaction, F=23.3) and VEGF (Group x Time interaction, F=46.14) increased in the exercise group and the Ex+CES group.
Fedor et al. (2015) [37]	60 older adults	Experimental; between-subject	6 consecutive days of water aerobics. Occurred once a day and was at a moderate-intensity.	MOCA, Trail Making, Stroop, Verbal Learning, and Figure Test.	The aquatic exercise improved executive function (P<0.001) and memory (P≤0.05) over the control participants, but not for attention (P=0.24).
Sato et al. (2015) [15]	21 elderly adults at least 65 + years	Experimental; between-subject	10-weeks of normal water-based exercise (Nor-WE) or cognitive water-based exercise (Cog-WE). The sessions were divided into two exercise series, a 10 min series of land-based warm up, consisting of flexibility exercises, and a 50-min series of exercises in water. The Nor-WE consisted of 10 min of walking, 30 min of strength and stepping exercises, and 10 min of stretching and relaxation in water. The Cog-WE consisted of 10 min of walking, 30 min of water-cognitive exercises, and 10 min of stretching and relaxation in water.	Attention, memory, learning, visuospatial cognition, and language fluency	Cog-WE improved attention (F=8.8, P=0.01), memory (F=8.3, P=0.01), and general cognitive function (F=8.8, P=0.01).
Schaefer et al. (2015) [9]	22 healthy adults (Mage=24 y) and single case patient with MCI	Experimental; within-subject	Completed cognitive task on land and in chest-deep water.	Auditory vigilance task	Listening errors were 42-45% lower for the water than land condition.
Ayan et al. (2017) [38]	51 healthy women	Experimental; between-	Water-based program for 6 months. First 3 months either focused on stimulating cognitive function via cognitive	Training-making and symbol digit cognitive	Water-based exercise program increased cognitive function,

	(Mage=46 y)	subject	tasks, with last 3 months focused on improving physical fitness. This order was reversed for half of the participants. Took place twice per week, in nonconsecutive 45-min sessions. The tasks that were used to stimulate cognitive function were derived from Brain Gym. A standard aqua fitness program was employed.	task	including for both the trail making ($P<0.05$) and symbol digit cognitive task ($P<0.05$).
Carral et al. (2017) [16]	37 older adults (Mage=67 y)	Experimental; between-subject	Water and land-based exercise program (EF group) or this same group plus cognitive training (EC group). Both the water and land sessions included 60 minutes of exercise, once per week, for three months	Symbol Digit task	Both groups improved their cognitive function. EF increased from 17.6 to 22.7 ($P<0.05$) and EC improved from 17.9 to 26.2 ($P<0.05$).
Becker et al. (2018) [12]	54-year-old woman diagnosed with early-onset Alzheimer dementia.	Case-study	19-weeks (17, 1-hr sessions) of warm water therapy. Therapy was progressive over time, including, for example, entering the water to treading the water for several minutes.	Cognitive communication	The patient improved their ability to cognitive communicate. Greater verbal articulation occurred over time.
Bressel et al. (2018) [14]	21 older adults (Mage=71 y)	Experimental; within-subject	Completed cognitive task on land and in chest-deep water.	Auditory vigilance task	Listening errors were 111% greater on land when compared to during water.
Pollock et al. (2018) [13]	31 individuals with multiple sclerosis (MS)	Experimental; between-subject	7 days of water aerobic exercises (40 min). Exercise began with a 5 min warm up, followed by 40 min of water aerobics, consisting of eight 4 minute intervals, with each interval separated by a 1 minute rest period. Intervals focused on different strength training activities (e.g., walking in water, bicep curls, etc.). Exercise concluded with a 5 min cool-down period of walking and stretching.	N-back cognitive task with fNIR assessment.	Following the week of exercise, O_2Hb increased ($P<0.05$) from rest to cognition (during the cognitive task).

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Author Contributions

Paul D. Loprinzi did all work for this paper.

Competing Interests

The author has declared that no competing interests exist.

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