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Effect of an Aquatic Environment on Dual-Task Performance in Older Adults

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EFFECT OF AN AQUATIC ENVIRONMENT ON DUAL-TASK PERFORMANCE IN OLDER ADULTS

by

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Abstract

Background: Older adults tend to have difficulty maintaining balance. It has been suggested that the aquatic environment may provide older adults with a safer and more challenging alternative to land for balance training. It has also been suggested that the performance of a dual cognitive-balance task paradigm may increase the competition for cortical resources needed to maintain balance. There is a need to evaluate the influence of an aquatic environment on the performance of a combined cognitive and motor task paradigm in older adults. **Purpose:** Utilizing a dual-task paradigm, the purpose of this study was to assess the effects of an aquatic environment on the performance of cognitive and motor tasks in older adults. **Design:** A quasi-experimental crossover research design was used. **Methods:** Twenty-one older adults (age = 71.7 ± 8.2 yrs) performed a cognitive (auditory vigilance) and motor (standing balance) task separately (single-task condition) and simultaneously (dual-task condition) on land and in water. Cognitive and motor performance measures were number of listening errors (auditory vigilance) and 95% ellipse area center of pressure (CoP) sway (balance), respectively. **Results:** A significant main effect for environment on listening errors was observed ($p = 0.001$, effect size [ES] = 0.82). Participants made 37.5% (single-task) and 72.3% (dual-task) fewer listening errors when performing the auditory vigilance test in water versus land respectively. A significant main effect of environment on CoP sway was observed ($p = 0.003$, ES = -1.19). CoP sway areas were 58.3% (single-task) and 64.4% (dual-task) greater in water versus land respectively. **Conclusion:** Results suggest that older adults make fewer ‘cognitive’ errors when immersed in water compared to on land. This may be beneficial to older adults who are involved in aquatic-based exercise and rehabilitation. Although CoP sway area increased, the aquatic environment may be safer than land exercises and provide a more challenging environment for training motor function such as balance in older adults.

Introduction

In 2003, the Center for Disease Control and Prevention (CDC.gov, 2006) released a report that stated more than 13,000 Americans aged 65 years old and older die each year from falling; and falling was the greatest reason for hospitalization for this age group (Hollman et al., 2006). In 2012, the number of deaths had increased from 13,000 to over 24,000 (Burns and Lee, 2016). Burns and Lee (2016) also found that fatal and nonfatal falls in older adults are a significant cost burden to the health care system in the United States. In the United States alone, fatal falls cost $637.5 million and nonfatal fall injuries cost $31.3 billion in 2015. These amounts are expected to increase with an aging population (Burns and Lee, 2016).

There are many factors that can contribute to fall risks in older adults. Dynapenia (Manini and Clark, 2011) and osteoporosis are age-related physiological changes that result in decreased muscle strength and power (dynapenia) and reduced bone mineral density (osteoporosis). In particular, deficits in muscle power have been observed to significantly predict fall risk (Pereira and Gonçalves, 2010), hospitalization (Legrand et al., 2014), and mortality (Legrand et al., 2014) in older adults. Simultaneous activation of muscles surrounding a joint, or co-activation has been shown to be an important falling risk factor (Gonçlaves, Pereira, Aguiar, 2008). In older women (70.7 ± 6.8 years old), Pereira and Gonçlaves (2010) reported that there was a significant correlation ($p < 0.05$) between the co-activation in maximum voluntary flexion/extension and the rate of force development in the knee. It was shown that as co-activation increased, rate of force development decreased, resulting in the decrease of the ability to recover from gait disturbances such as falling (Pereira and Gonçlaves, 2010).

Fall risk in older adults is also dependent on cognitive functioning. For example, a meta-analysis conducted by Muir, Goaul, and Odasso (2012) revealed that cognitive impairment is a risk factor for falling episodes in older adults. In a recent study by Franssen et al. (1999), equilibrium and limb coordination was estimated by having older participants (70.4 ± 9.4 years old) with mild cognitive impairment and Alzheimer's disease perform a single leg stance followed by a tandem walk. Subjective observations were performed by physicians who rated the performance of the balance and walking tasks using a 7-point rating scale. Parametric tests that assessed balance performance and limb coordination revealed that participants with cognitive impairment were not able to maintain equilibrium as well on both the single leg stance and the tandem walk when compared to adults with no cognitive impairment. The results of this study suggest that balance is affected by cognitive impairment and that further research could help explore types of exercise that may improve balance in older adults with cognitive impairment.

Physical therapists may prefer to use an aquatic environment for balance training and rehabilitation in older adults since it provides several unique features that are difficult to replicate on land. For instance, the aquatic environment provides a setting where the likelihood of injury from a fall is not as great compared to land. In addition, the aquatic environment may facilitate the performance of exercises that challenge postural control in certain populations, including older adults (Bressel et al., 2014).

Exercise and rehabilitation in an aquatic environment may be particularly beneficial in older adults with cognitive impairment. For instance, when a body is immersed in water, hydrostatic pressure surrounding the extremities acts as a large hosiery (compression sock). The effects of hydrostatic pressure have been shown to increase cardiovascular and musculoskeletal function (Denning et al., 2012), and increase cerebral cortex activity in both sensory and motor activities (Sato et al., 2012).

One reason for the observed increase in cortical activation could be increased cerebral blood flow. Pugh et al. (2014) found that cerebral blood flow increased when young adults (24 ± 4 years old) were immersed in water when at rest, during exercise, and after the exercise treatment. In addition to increased blood flow, water also affects the load on the joints of the human body due to the buoyancy properties. Buoyancy can off-load the weight placed on the joints of the human body by approximately 39% when immersed in water to the greater trochanter, and approximately 68% when lowered to the xiphoid process (Louder et al., 2014). Bressel et al. (2014) found that after a 6-week balance and high intensity interval training program in the aquatic environment, using a visual analog scale (VAS) participants reported lower joint pain (50.3mm pre-test compared to 15.8mm post-test), and improved balance using the Limits of Stability test (pre-test = 66.6 vs. post-test = 73.5).

Dual-task paradigms can be used to assess whether motor and cognitive tasks compete for the same cortical resources. Dual-task paradigms require an individual to perform and focus on two different tasks at the same time. Dual-task performance is then compared against the performance of each task alone. To assess the influence of an aquatic environment on the level of cognitive involvement required to maintain equilibrium, Schaefer et al. (2015) asked young adults to perform a dual-task paradigm of listening and balance on land and in chest-deep water. Results showed that listening errors improved by 42% and 45% in the aquatic environment versus land for both single and dual-task conditions (ES = 0.38 and 0.55). The results also indicated that mean 95% ellipse center of pressure (CoP) sway area decreased in both the land and water environments over a 90 second trial, when participants were performing the dual-task paradigm compared to the single-task condition. Limitations to this previous study done by Schaefer et al (2015), however, include the relatively young age of the participants and the lack of difficulty associated with the motor task.

Knowing that older adults tend to have difficulty maintaining equilibrium, there is a need to evaluate the influence of an aquatic environment on the performance of a combined cognitive and motor task paradigm in older adults. Utilizing a dual-task paradigm, the purpose of this study was to assess the effects of an aquatic environment on the performance of cognitive and motor tasks in older adults. For this study, it was anticipated that the effect of an aquatic environment on dual-task performance would increase measures of postural sway and improve performance of a cognitive listening task in older adults.

Methods

This study was a quasi-experimental crossover research design where the same group of participants preformed a dual-task paradigm in two different environments: on land and in water up to the xiphoid process in a single test session. Performance outcome measures from the dual-task conditions were listening errors (cognitive task) and CoP sway area (motor task). Data collection took place in a climate-controlled room in a clinical facility. Temperature was regulated at 24°C for the air, and 30°C for the water.

Participants

Twenty-one older adults were asked to participate in the study which involved attending a single test session. Physical characteristics of the participants are presented in Table 1. Inclusion criteria for this study were as follows: the participants must be able to stand up from a seated position, and must be able to pass an auditory test. The exclusion criteria used to determine participant eligibility was as follows: lower-extremity injury that impedes balance, sensory dysfunction (neural, vestibular and visual) or a concussion 12 weeks prior to the study. Additionally, if the participant scored below a 16 on the MoCA test, or missed more than three of the six (50%) numbers/letters in either ear on the Whisper Test, the participant was not permitted to participate in this study. Participants for this study were recruited from the local community centers (via a flyer), local postings, and/or by word of mouth. All participants were required to sign an informed consent form approved by the university Institutional Review Board.

Experimental Procedures

Participants were first given the Montreal Cognitive Assessment test (MoCA) to screen for mild to severe cognitive impairment. Previous research has found the MoCA test to be a reliable examination for evaluating varying levels of cognitive impairment in adults showing mild to severe forms of cognitive impairment (Koski, 2013, Nazem et al, 2009). The MoCA took approximately 10 minutes to administer and was scored following the MoCA Administering and Scoring Procedures. Points were scored for a total of 30; a score of 26 or greater was considered normal cognitive competency, anything below 26 points showed signs of cognitive impairment. All participants' scores were recorded and analyzed.

The MoCA took participants through a series of seven question sets including: a visual/executive where the participant was asked to trace a pattern correctly, a naming section where the participant was asked to correctly name certain objects from a picture, a memory section where the participant was asked to repeat a series of five words, an attention section where the participant was asked to repeat digit recall, a language section where the participant was asked to repeat a sentence back correctly, an abstraction question where the participant was asked what different types of objects have in common, and a delayed recall question where the participant was asked to repeat words with and without certain verbal cues. Participants were provided an orientation to the testing, if desired.

The participants were then given the Whispered Voice Test as a screening to assess for proper hearing. The Whisper Voice Test was administered following the testing criteria from a previous study (Pirozzo, Papinczak, and Glasziou, 2003). The procedures for the test were as follows: The administrator stood behind the participant's field of vision to eliminate the possibility of lip reading (the same administrator was used for all trials to obtain consistency). The participant occluded the non-testing ear with his or her hand. The participant was then asked to repeat a set of 3 different numbers at varying distances (6 inches and 18 inches away from participant's head) at both normal conversation and whispering loudness levels. A passing score was given if the participant could repeat all three numbers correctly at each level of loudness (Table 1), or achieve greater than 50% success over three successive triplet sets. Failure to pass (≥ 50%) at each of the loudness levels was considered a positive for hearing impairment. Participants also performed the Timed Up and Go (TUG) test in accordance with a previous study (Basset, Sui, and Honaker, 2017). Results were used as a descriptive statistic.

Participants were given an opportunity to become familiar with the experimental testing procedures and performed the single-task and dual-task conditions on land. After familiarization, participants began testing under single-task and dual-task conditions in which they performed a cognitive and a motor task separately (single-task) and then together (dual-task) both on land and in water. The environment order land-then-water was assigned to minimize participant's shaking and shivering which could compromise postural sway. The task condition (single or dual) within each environment was randomly assigned.

The cognitive task was a modified version of an auditory vigilance test previously described (Schaefer et al., 2015). For this study, the cognitive task required participants to listen to a 90-second sequence of four letters (A, G, M and O) repeated in a random order, then verbally report the number of times a target letter was heard. The cognitive task was performed by itself (i.e. single-task condition), where the participants were seated both on land and immersed in water to the level of the xiphoid process to obtain a base comparison. Participants were asked to: "Listen for the target letter A, G, M, or O and count how many times you hear this letter without using your fingers to help you count." When the cognitive task was being performed simultaneously with the motor task while standing, the participants were asked to: "Focus on the mark in front of you, hands on your hips, stand as still as possible, and listen for the target letters (A, G, M, and O) and count how many times you here this letter without using your fingers."

Using headphones set at a comfortable listening level (determined prior to testing by participant in a trial run), 8 randomized, previous recordings of 144 letters were presented at 1.6 hertz over 90-seconds with a range of 30 to 44 target letters per trial (Schaefer et al., 2015). The target letters were randomly assigned during each trial. The number of listening errors per trial was the outcome measure for the cognitive performance task. The absolute value for the errors was recorded to account for over or under estimation of the actual amount of target letters.

The motor task required participants to stand for 90 seconds in a modified tandem stance (one foot placed off-set in front of the other) without shoes on a force-platform. The tandem stance has been shown to be a more complex pattern or challenging stance when analyzing CoP compared to double-leg stance or a staggered stance, specifically in the mediolateral direction (Wang, Newell, 2015). Participant's CoP was measured on a force platform (Model OR6-WP, Advanced Mechanical Technology, Inc., Watertown, MA, USA) without shoes. The force platform was positioned on an adjustable aquatic treadmill (HydroWorx 2000, HydroWorx, Middleton, PA, USA) to allow the participant to be lowered to the xiphoid process while standing or seated. The force platform was marked with positions as to where to place the feet in order to keep data consistent through trial conditions. Additionally, participants were asked to minimize movement in the water (wait approximately two minutes) before each trial to suppress fluid currents that may affect force platform measurements. Center of pressure (postural sway) was measured as the outcome variable for the motor task performance. The measurements were analyzed using BioAnalysis software (version 2.2; Model OR6-WP, Warton, MA, USA).

Statistical Analysis

The performance measures for both the cognitive and motor tasks were individually compared between the two environments (land and water) and the conditions (single-task and dual-task) using two separate 2 (Environment) × 2 (Task) repeated measures analysis of variance (ANOVA). A p-value of 0.05 was used to determine statistical significance. Data was analyzed with SPSS statistical software programming. Cohen's d (Cohen, 1988) effect size (ES) was used to evaluate meaningfulness of statistically significant results, using a pooled standard deviation, with ES of 0.2, 0.5, and 0.8 corresponding to small, medium, and large ES respectively.

Results

All participants completed the testing as planned except for one participant who did not feel comfortable getting in water.

Listening Errors: Using an ANOVA to analyze the listening errors revealed a significant main effect for the environment factor (F = 11.4, p = 0.001, n^2 = 0.125, ES = 0.82). These results indicate that fewer listening errors were made in water versus on land. There was no main effect (Table 2) observed for the task condition (F = 1.6, p = 0.214, n^2 = 0.019, ES = 0.25). There was also no interaction between environment and task (F = 0.8, p = 0.371, n^2 = 0.010) suggesting that listening errors were consistently different between environments regardless of the condition.

Balance: Statistical analyses of CoP area revealed a significant main effect for environment (F = 9.6, p = 0.003, n^2 = 0.110, ES = -1.19). These results suggest that participants swayed more in the aquatic environment. No main effect (Table 3) was shown for the task condition (F = 1.5, p = 0.225, n^2 = 0.019, ES = 0.08). There was also no interaction between environment and task for this measures (F = .11, p = 0.734, n^2 = 0.001).

Discussion

The purpose of this study was to test how the aquatic environment affected balance and cognition in older adults. The most interesting observation was that older adults made significantly fewer listening errors when immersed in water for both single and dual-task conditions (Table 2). These findings were consistent with research done by Schaefer et al. (2015) who found that young adults (24.3 ± 5.2 years old) made 42% and 45% fewer listening errors in the water environment regardless of whether the cognitive task was performed by itself or at the same time as the motor task.

One reason for the fewer listening errors made in water could be a lower perceived risk of falling. For instance, Bressel, Louder, and Dolny (2016) observed visual analog scale (VAS) pain scores were lower in older adults in water at the hip level (12.5 ± 10.9 mm) compared to younger adults (14.9 ± 8.5 mm) on levels of stability, indicating that older adults felt more stable in the water compared to younger adults respectively. Other research suggests that there may be physiological reasons for increased cognition when older adults are immersed in water (e.g. cerebral blow flow) resulting in fewer listening errors (Pugh et al., 2014). Using functional near-infrared spectroscopy (fNIRS), Sato et al. (2012) showed that sensory and motor areas in the cerebral cortex increased in activity when healthy adults were immersed in water up to the hip. The increase of cortical activation may also have contributed to the decrease in listening errors found in this current study.

It was also found that the water environment trials produced significantly larger sway areas compared to the land trials (Table 3). This increase in sway area could be interpreted as a decrease in balance. Studies have shown that when the body is immersed in water, the whole body center of gravity and unloading of body weight the buoyancy effect water is shifted higher, resulting in an increase in postural sway from 2.3 cm^2 on land compared to 7.8 cm^2 in water (Louder et al., 2014) and similar results were found from Harrison et al. (1992) who reported 1.8 - 2.4 cm^2 on land to 6.9 - 9.4 cm^2 in water. An increase in postural sway is concurrent with findings from Schaeffer et al. (2015) who found that younger adults produced similar increased postural sway results. In the previous study (Schaefer eta al., 2015), participants performed a similar motor task, where a double-leg stance was used (balancing on a force platform) and the same cognitive task (listening for target letters) under the same conditions: both on water and on land. Schaeffer and colleagues found that the younger swayed 115% and 164% more in the water conditions.

Other research has shown that dual task training programs helps improve postural sway on land compared to just balancing (Povtin-Desrochers, Richer, Lajoie, 2017). Povtin-Desrochers and colleges found that when older and younger adults performed a cognitive task, while balancing on a force platform, participants produced smaller sway areas (2017). These results suggest that older and younger adults who undergo cognitive testing concurrently with a motor task promotes postural sway stability.

In this study, the MoCA test was used as a screening test for cognitive impairment; however, results of the test on these older adults only showed mild signs of mild cognitive impairment in two of the participants who scored below 26 points, all other participants scored above 26 points. The MoCA test used may not have been sensitive enough for the given sample population. There may be other tests that are more sensitive to screen for mild cognitive impairment in older adults. Shin et al. (2011) found that older adults with cognitive impairment (72.1 ± 4.1 years old) produced significantly greater ($p < 0.05$) sway in the mediolateral direction when compared to a control group (71.5 ± 3.7 years old). Evaluating how older adults with cognitive impairment compare to this present study could add further insight and research into how aging and cognitive impairment affects a dual-task paradigm of listening and balance.

One limitation to this study that was verbally expressed through many of the participants was the differentiation between the letters for the listening task. For example, many participants stated that they couldn't differentiate between the letter "M" and the letter "N", even though there was no "N's" in the listening sequence. Using letters that are on different frequencies might help solve this problem. Another limitation to this study could be how sway is influenced by the height of the participant.

Conclusion

Results from this study suggest that older adults tend to make fewer listening errors while immersed in chest deep water than on land. This may be beneficial to older adults who are involved in aquatic-based exercise and rehabilitation and may provide a practical and safer environment to challenge postural balance and help improve cognitive functioning. Performing these same tasks and conditions in older adults with mild to severe cognitive impairment could further research in this field by helping patients challenge balance and help provide rehabilitation therapies or training programs for prevention for falling-related injuries and deaths. Using other dual-task paradigms such as listening and walking, may provide a more functional insight for effective therapy prescriptions in adults who struggle cognitively or have problems maintaining balance.

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Table 1. *Participant Characteristics (mean ± standard deviation, range)*.

	Male (n = 9)	Female (n = 12)	n = 21
Age (years)	73.22 ± 8.57	70.50 ± 8.12	71.7 ± 8.2 (56, 87)
Mass (kg)	79.35 ± 11.87	70.11 ± 13.56	74.1 ± 8.0 (53.5, 94.7)
Height (m)	1.79 ± 0.01	1.60 ± 0.04	1.70 ± 1.1 (1.56, 1.8)
MoCA (points)	27.71 ± 3.35	28.17 ± 2.25	28.0 ± 2.7 (19, 30)
Timed Up and Go (sec)	8.7 ± 0.9	8.9 ± 1.4	8.8 ± 1.2 (6.5, 11.5)
Whisper Test (%)	100 ± 0.0	100 ± 0.0	100 ± 0.0 (100, 100)

Table 2. *Listening Errors (mean ± SD # of errors). Participants made fewer listening errors in water than on land (*p < 0.001) regardless of task.*

	Land	Water	Total
Single-Task	3.5 ± 2.9	2.2 ± 2.2*	2.9 ± 2.7
Dual-Task	3.4 ± 2.3	1.3 ± 1.3*	2.3 ± 2.1
Total	3.5 ± 2.6	1.7 ± 1.8*	

Table 3. *95% Ellipse Sway Area (mean ± SD* cm^2*). Participants swayed more in water than on land (*p < 0.003).*

	Land	Water	Total
Single-Task	7.1 ± 5.8	12.0 ± 6.3*	6.4 ± 6.4
Dual-Task	5.2 ± 3.2	13.1 ± 6.0*	8.9 ± 6.1
Total	6.1 ± 4.7	12.5 ± 6.1*	