RESEARCH ARTICLE

Effect of Water Immersion on Dual-task Performance: Implications for Aquatic Therapy

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Abstract

Background and purpose. Much is known about cardiovascular and biomechanical responses to exercise during water immersion, yet an understanding of the higher-order neural responses to water immersion is unclear. The purpose of this study was to compare cognitive and motor performance between land and water environments using a dual-task paradigm, which served as an indirect measure of cortical processing. Design. A quasi-experimental crossover research design is used. Methods. Twenty-two healthy participants (age = 24.3 ± 5.24 years) and a single-case patient (age = 73) with mild cognitive impairment performed a cognitive (auditory vigilance) and motor (standing balance) task separately (single-task condition) and simultaneously (dual-task condition) on land and in chest-deep water. Listening errors from the auditory vigilance task and centre of pressure (CoP) area for the balance task measured cognitive and motor performance, respectively. Results. Listening errors for the single-task and dual-task conditions were 42% and 45% lower for the water than land condition, respectively (effect size [ES] = 0.38 and 0.55). CoP area for the single-task and dual-task conditions, however, were 115% and 164% lower on land than in water, respectively, and were lower (≈8–33%) when balancing concurrently with the auditory vigilance task compared with balancing alone, regardless of environment (ES = 0.23–1.7). This trend was consistent for the single-case patient. Conclusion. Participants tended to make fewer ‘cognitive’ errors while immersed chest-deep in water than on land. These same participants also tended to display less postural sway under dual-task conditions, but more in water than on land. Copyright © 2015 John Wiley & Sons, Ltd.

Received 14 April 2014; Revised 17 December 2014; Accepted 25 February 2015

Keywords
aquatic therapy; brain activity; hydrotherapy; postural sway; rehabilitation

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Published online 17 April 2015 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/pri.1628

Aquatic physical therapy includes treatment, rehabilitation, prevention, health, wellness and fitness of patient populations in an aquatic environment. Numerous studies have examined cardiovascular and musculoskeletal responses to aquatic physical therapy exercise, compared with land-based exercises with a focus on oxygen consumption, heart rate, pain, gait stride length and functional gain comparisons (Denning et al., 2012). To date, however, higher-order neural responses to water immersion and exercise have not been studied extensively.
Determining how water immersion influences brain activity is critical for understanding the full benefits of aquatic physical therapy. For example, some populations who undergo such therapy (e.g. stroke, elderly) may have abnormal patterns of cortical activation, particularly in sensory-related and motor-related structures (Miyai et al., 2002). The known properties of water (e.g. hydrostatic pressure) may potentially enhance cortical activation specifically in sensorimotor areas when an individual is immersed in water during a session of aquatic therapy. In fact, water immersion to hip level has recently been shown to increase activity in both sensory and motor areas of the cerebral cortex in healthy adults, as measured by functional near-infrared spectroscopy (fNIRS) (Sato et al., 2012). Deeper water immersion (to axilla) has also been shown to attenuate motor-evoked potentials in upper extremity musculature, as measured by transcranial magnetic stimulation (TMS), suggesting a water-related reduction in inhibitory signals from the somatosensory cortex to motor areas (Sato et al., 2013). Evidence from these studies suggests the aquatic environment may be effective not only for musculoskeletal rehabilitation but also for neurorehabilitation (e.g. reacquisition of motor task), given that cortical activation patterns related to a given motor task may be different in water compared with on land.

Quantifying such differences in cortical activity in water compared with on land is, however, quite challenging. Even portable technologies for measuring cortical activity, such as fNIRS and TMS, are cumbersome, expensive and more importantly, highly influenced by skin temperature and blood flow changes. Both of these factors change substantially during water immersion. For instance, water immersion to the chest increases central blood volume and decreases heart rate (Wilcock et al., 2006), which can complicate fNIRS variables such as oxygenated haemoglobin concentrations (Ferrari et al., 2004). Accordingly, there is a need to better understand how water immersion influences cortical activity using assessments that do not have the limitations of fNIRS and other brain-imaging techniques.

One solution might be to use an indirect yet valid behavioral measure known as dual-task interference. Conceptually, if two separate tasks rely on a common set of neural circuits or require high levels of attention, then simultaneous performance of these tasks will result in ‘interference’ due to competing demands for neural resources (Passingham, 1996). Evidence of interference is typically measured as decreased performance of one, or both, tasks under dual-task conditions relative to performance on their own (Woollacott and Shumway-Cook, 2002). For example, a postural balancing task performed in water might be associated with increased brain activity relative to on land, which is consistent with previous findings for healthy adults (Sato et al., 2012). If so, one might hypothesize that more dual-task interference will be observed when the postural task is performed simultaneously with a non-motor cognitive task (e.g. auditory vigilance) in water than on land because there will be less available neural resources to complete the task(s).

The purpose of this present study was to address this hypothesis with a dual-task paradigm that used a cognitive task (auditory vigilance) and motor task (standing balance). The proposed hypothesis is based on research using healthy older adults (Sato et al., 2012), which were tested in the current study. A secondary purpose was to assess if the findings extended to a single-case patient with mild cognitive impairment. The results of this study will add to the current body of knowledge regarding brain activity differences between land and water environments.

**Methods**

This study used a quasi-experimental crossover research design where the same group of participants performed a dual-task paradigm in two different environments: on land and in chest-deep water. Performance outcome measures from the dual-task conditions were listening errors (cognitive task) and centre of pressure (CoP) sway area (motor task). Data collection took place in a climate-controlled room in a clinical facility. Air temperature and water temperature were regulated to 24°C and 30°C, respectively.

**Subjects**

Twenty-two healthy younger adults (male = 12 and female = 10) were asked to participate in the study and to attend a single test session. Physical characteristics of the participants were (mean ± standard deviation) as follows: age = 24.3 ± 5.24 years, mass = 75.5 ± 17.1 kg and height = 1.75 ± 0.04 m. The exclusion criteria used to determine participant eligibility were as follows: lower-extremity injury that impedes balance, sensory dysfunction (neural, vestibular and visual) or a concussion in...
the 12 weeks before the study. The sample size was based on effect sizes (ES) computed from previous studies using a similar dual-task paradigm (Schaefer and Lang, 2012) with an \( \alpha \) of 0.05 and \( \beta \) of 0.80.

The patient for the case study was recruited from the local community (via a flyer) and was part of a larger project examining how age influences balance in an aquatic environment. The patient was a 73-year-old woman (mass = 71.2 kg) who satisfied the aforementioned exclusion criteria. In terms of medical history, the patient reported that she was generally healthy and was not on medications that would interfere with her balance or her ability to listen and memorize letters. Additionally, the patient denies having a history of stroke or head injury. The patient scored 24 out of 30 on the mini-mental state examination, which was interpreted as mild cognitive impairment. The patients score was not adjusted for educational attainment or age as they were not outside the recommended range. All participants were required to sign an informed consent form approved by the university institutional review board.

**Procedures**

Procedures for the experimental and case study were identical. Participants were first given an opportunity to become familiar with the experimental testing procedures and performed the single-task and dual-task conditions described later in the text on land. After familiarization, participants commenced testing under single-task and dual-task conditions in which they performed a cognitive and motor task separately (single task) and together (dual task) on land and in water. The environment order (land-then-water vs. water-then-land) was unsystematically assigned, and the task condition (single or dual) within each environment was randomly assigned except for the cognitive task under single-task conditions (i.e. by itself), which was always performed first in the sequence to minimize shivering.

The cognitive task was a modified version of an auditory vigilance test previously described (Schaefer and Lang, 2012; Schaefer et al., 2013). In this study, the 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. Additional details regarding this task are described later in the text. When the cognitive task was performed by itself (i.e. single-task condition), participants were seated on land and immersed in water at the level of the xiphoid (Figure 1). Participants were explicitly asked to: “Listen for the \(<\text{target letter A, G, M, or O}>\) and count how many times you hear this letter without using your fingers to help you count.” When the cognitive task was performed simultaneously with the motor task (i.e. dual-task condition) described
in the succeeding text, participants stood (Figure 1) and 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 letter A, G, M, or O> and count how many times you hear this letter.’

The 144 letters were presented at a 1.6 Hz frequency (1.6 Hz = 144 letters × 90 s) using headphones (Skullcandy, Model Hesh, Park City, UT, USA) with a comfortable volume. The target letter for each trial (A, G, M or O) was randomly assigned. The measure of cognitive task performance was the number of listening errors per trial. The number of listening errors was calculated as the difference between the reported and correct number of times the target letter was heard. This difference was expressed as an absolute value, such that a participant could have errors by either over-estimating or underestimating the number of target letters (Lang and Bastian, 2002). For statistical comparison, we did not consider the directionality of the estimation (over vs. under), but instead modelled ‘ideal’ listening performance as zero error. Thus, either an overestimation or underestimation of target letters was considered equally erroneous in this study, with more deviation from zero, indicating poorer performance (see statistical analyses later in the text). This cognitive task has been used previously to show dual-task interference in healthy and neurologically impaired populations regardless of their intelligence or education levels (Schaefer and Lang, 2012; Schaefer et al., 2013). Moreover, this cognitive task has been shown to be resistant to learning effects in these populations (Lang and Bastian, 2002), such that practicing this task by itself does not yield significant within-session improvements.

The motor task required participants to stand for 90 seconds in a double-leg stance without shoes on a waterproof force plate (Model OR6-WP, Advanced Mechanical Technology, Inc., Watertown, MA, USA; Figure 1) using methods and equipment described previously (Louder et al., 2014). The force plate was positioned on an adjustable-depth floor of an aquatic treadmill (HydroWorx 2000, HydroWorx, Middletown, PA, USA). The adjustable-depth floor facilitated placement of the force plate out of the water (land environment) and in the water, such that participants were submerged to the xiphoid process (water environment). Water-resistant chalk was used to place target marks on the force plate surface to ensure consistency of foot placement across conditions. Additionally, participants were asked to minimize motion in the water for at least 2 minutes before each trial to suppress fluid currents that may affect force plate measurements (Louder et al., 2014). Once participants were in position to perform the motor task by itself, they were asked to: ‘Focus on the mark in front of you, hands on your hips, and stand as still as possible.’

The measure of motor task performance was the mean 95% ellipse CoP sway area (or CoP area) over the 90-second duration. CoP area is a widely used measure of balance (Ruhe et al., 2010; Moghadam et al., 2011) with high reported reliability coefficients (e.g. 0.86) (Moghadam et al., 2011). Additionally, CoP area is considered an effective measure of balance control (Prieto et al., 1996) and displays similar trends to other balance measures (e.g. CoP velocity) during aquatic research (Louder et al., 2014). Generally speaking, lower values of CoP area indicate better balance, as evidenced by its covariance with risk of falling (Woollacott and Shumway-Cook, 2002). The CoP area measurement was computed from kinetic data from the force plate (25 Hz sample rate) and BioAnalysis software (version 2.2; Advanced Mechanical Technology, Inc., (AMTI) Model OR6-WP, Watertown, MA, USA). The force plate and acquisition hardware were calibrated according to manufacturer guidelines and were shown to be repeatable using our methods and equipment (coefficient of variability ≈ 3%) (Louder et al., 2014).

Statistical analysis

Performance measures for the cognitive (listening errors) and motor (CoP area) tasks were individually compared between environments (land and water) and condition (single task and dual task) using 2 × 2 repeated measures analysis of variance (ANOVA) with an α level set to 0.05. The meaningfulness of any statistical difference was compared using ES calculations and coefficients by Cohen (1988). Data from the case study were analyzed descriptively.

Results

All participants completed testing as planned. Regarding listening errors, the ANOVA revealed a significant main effect for the environment factor (F = 12.3, p = 0.002). There was no effect for the condition factor (p = 0.72) or the environment by condition interaction (p = 0.80), suggesting that listening errors were
consistently different between environments regardless of condition. Figure 2 shows that listening errors for the single-task and dual-task conditions were 42% and 45% lower for the water than land condition, respectively (ES = 0.38 and 0.55).

Regarding CoP area, the two-factor ANOVA revealed a significant main effect for environment ($F = 72.3, p = 0.001$) and condition ($F = 5.70, p = 0.03$) factors. There was, however, no environment by condition interaction ($p = 0.64$). Figure 3 shows that CoP area for the single-task and dual-task conditions were 115% and 164% greater for the water than land environment, respectively (ES = 1.7 and 1.6). Much smaller differences were observed between conditions. For example, CoP area was 33% (land) and 8% (water) greater between the single-task and dual-task conditions, respectively (ES = 0.75 and 0.23).

It was observed that listening errors and CoP area values for the case study patient followed the same trend as those for the healthy group. For example, listening errors on land (six errors) were greater than in water for the single-task condition (four errors). Additionally, CoP area in water (12.8 cm$^2$) was greater than on land (6.8 cm$^2$) with a slight increase in values for the single-task condition.

**Discussion**

Results did not necessarily support the hypothesis of more dual-task interference (i.e. more listening errors and/or higher CoP area) in water relative to on land. Instead, less interference was observed in water than on land, as evidenced by fewer listening errors in the water environment compared with the land environment, regardless of whether the cognitive task was performed by itself or at the same time as the motor task. Additionally, CoP area was lower for the dual-task condition compared with the single-task condition, regardless of environment. This trend was consistent for an older adult with mild cognitive impairment.

The number of listening errors in this study (overall $\bar{x} = 1.5$) is consistent with previous research using a similar cognitive task and participant group ($\bar{x} = 1.2$) (Schaefer and Lang, 2012). One reason why listening errors were not greater in water than land, despite potentially higher sensorimotor brain activity (Sato et al., 2012), may be a change in underlying parasympathetic neural drive. Studies have consistently observed that hydrostatic pressure during head-out of water immersion shifts peripheral blood volume to the thoracic region, thereby increasing central blood volume and stroke volume (Arborelius et al., 1972; Epstein et al., 1981; Johansen et al., 1997). This haemodynamic event increases pressure within arterial and venous structures and stimulates baroreflexes, which are thought to elevate vagal tone and parasympathetic drive (Pump et al., 2001). Reduced heart rate, heart rate variability, blood pressure, plasma cortisol and aldosterone concentrations in thermoneutral water compared with on land supports this conjecture (Sramek et al., 2000; Al Haddad et al., 2010). Moreover, features of greater parasympathetic drive, such as reduced heart rate variability, are associated with improved cognitive performance (Van Roon et al., 2004; Duschek et al., 2009).
and may in part explain why participants in the current study displayed fewer listening errors in water than land regardless of condition (single or dual; Figure 2). This conjecture will indeed need to be tested formally in future research.

In addition, CoP sway measurements in this study (e.g. water environment = 12.8 cm²) were consistent with previous related research (≈11.0 cm²) (Louder et al., 2014), with higher values in water than on land (Figure 3). This observation has been discussed previously and may be partly explained by (1) the unloading of body weight (≈68 ± 3%) due to buoyancy and (2) the raising of whole body centre of gravity to reduce stability and coordination of postural movements required to maintain balance (Louder et al., 2014). The added postural sway in an aquatic environment might in fact be beneficial for some populations (e.g. pathologically impaired and the elderly) who need a safe environment to challenge postural control strategies during the early phases of rehabilitation, especially if these approaches lead to improvements in physical function and reduced risk of falls (Dibble et al., 2009).

The CoP sway areas in the current study were statistically lower during dual-task versus single-task conditions, regardless of the environment (Figure 3), albeit the differences in sway between tasks may not be clinically relevant as evidenced by the small effect size for the water condition (ES = 0.23). Nevertheless, we predicted the concurrent performance of the cognitive and motor tasks would produce greater competition for limited attention resources, which would result in greater CoP sway areas under dual-task conditions compared with baseline (i.e. single-task condition) values. This hypothesis largely depended on whether the cognitive or motor tasks were sufficiently difficult enough to generate competing demands in our participants (Huxhold et al., 2006). For example, dual-task conditions may increase postural sway (Andersson et al., 1998) or decrease postural sway (Dault et al., 2001), depending on relative task difficulty and participant age (Passingham, 1996; Woollacott and Shumway-Cook, 2002; Huxhold et al., 2006). Certainly, the postural motor task in the current study (double-leg stance) was not difficult as evidenced by the minimal CoP sway areas in the elderly single-case patient. However, the rate of the letter sequences in the cognitive task (1.6 Hz) approached maximal frequency for perceptual sensitivity in young adult participants (Neelon et al., 2011). Moreover, participants in our study verbally expressed the cognitive task by itself as being ‘challenging’. Collectively, the combination of task(s) and sample (i.e. younger participants) in the current study may not have been sufficient enough to produce dual-task interference and subsequent increase in postural sway area.

Nevertheless, future research could use other dual-task paradigms to probe changes in cortical or subcortical responses due to water immersion by testing older participants and using more difficult motor tasks such as tandem stance or walking. This approach is logical given that in the real world, standing or walking is typically performed concurrently with at least one other task (e.g. standing or walking while listening to others or talking). In this view, comparisons of dual-tasking between water and land environments may provide functional insights that may help the prescription of aquatic therapy be more effective for and tailored to populations with known cognitive and balance deficits.

**Implications for physiotherapy practice**

With respect to the clinical significance of this study, effect sizes were generally small to medium (except the large effect sizes related to CoP area comparisons) when using Cohen’s convention (Cohen, 1988). Taken together, the results of this study suggest that healthy participants sway more yet make fewer ‘cognitive’ errors in water than on land. Given that some populations (e.g. stroke, elderly) may display a decline in sensorimotor and cognitive function (Miyai et al., 2002), water immersion may be a viable and time-effective environment for challenging cognitive function and balance within the same therapy session. Data from the elderly single-case patient seem to support this contention.

**Conclusion**

Healthy younger adults tended to make fewer listening errors while immersed chest-deep in thermoneutral water than on land. These same participants also tended to display less postural sway under dual-task conditions, compared with balancing alone, but had more postural sway in water than on land. This trend seems to be consistent when these tasks are performed by an older adult who displays mild cognitive impairment.
Conflict of interest
The authors declare no conflict of interest.

Acknowledgement
This study was supported by grants from the National Swimming Pool Foundation.

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