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EFFECT OF WATER IMMERSION AND JET PERTURBATION ON BALANCE IN OLDER AND YOUNGER  
ADULTS

By

Matthew Baldwin

A Plan B paper submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

In

Health and Human Movement

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Logan, Utah

# Effect of Water Immersion and Jet Perturbation on Balance in Healthy Older and Younger Adults

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## Disclosures

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## Abstract

**Background:** Although balance exercises are often performed in shallow pools, the efficacy of this practice is not well understood.

**Purpose:** To quantify the effect of water depth and jet intensity on measures of balance in older and younger adults.

**Subjects:** Sixteen older (age =  $62.8 \pm 9.56$  yrs) and fifteen younger (age =  $22.5 \pm 1.85$  yrs) adults.

**Methods:** Posturography data were collected as participants stood quietly for 90 seconds on land and at various water depths and jet intensities.

**Results:** Main effects ( $p < 0.001$ ) and pairwise comparisons revealed that all measurements increased with increasing water depth and jet intensity, with older adults increasing statistically less than younger adults at higher jet intensities.

**Conclusions:** Water immersion to the xiphoid process and water jet intensities at or above 40% seem to be environmental conditions that produce the greatest postural sway.

**Keywords:** postural sway, center of pressure, aquatic, water, older adults

## 1. Introduction

Balance, operationally defined, is the ability to maintain an upright position while reacting to possible postural perturbations.<sup>1-4</sup> Regulation of balance during static and dynamic mobility tasks requires the interaction of the central nervous system, the musculoskeletal system, and various sensorimotor systems.<sup>2,4,5</sup> Each of these systems may be compromised with age, leading to decreased balance and increased incidence of falls in older adults.<sup>6,7</sup> As a result, many older adults limit their activities to minimize risk of falling<sup>7</sup>, further decreasing functionality and exacerbating the issue of decreased balance.

Primary rehabilitative goals focus on improving balance, along with mobility and function, through balance training exercises. Commonly prescribed exercises include standing on one foot, standing on foam or ankle discs, and performing lower extremity exercises.<sup>2,3,6-10</sup> Typically, balance training is performed on land. However, due to the higher incidences of falls in older adults, it is not uncommon for clinicians to prescribe balance exercises in a shallow pool.<sup>3,7,11</sup>

There is some conjecture that the viscous properties of water improve postural error detection by increasing the time allowed for postural reflex adjustments.<sup>7</sup> This viscous feature of water is also thought to reduce the fear of falling among older adults; making the aquatic environment potentially efficacious for balance training.<sup>7</sup>

For example, results of a study examining center of pressure (CoP) sway (e.g., 95% ellipse area, mean velocity) during quiet stance on land versus in water reported that postural sway measurements progressively increased as water depth increased.<sup>12</sup> Whether or not increased sway during water immersion is detrimental to balance exercises is not well

understood. Prior studies have revealed that older adults at risk for falling exhibit greater postural sway compared to young, healthy controls.<sup>13</sup> Conversely, Hamill et al. observed decreased sway during quiet, double leg stance in older adults compared to young, healthy controls and suggest that sway variability may actually improve balance so long as the basic task needs are met.<sup>14</sup>

Additionally, Louder et al. observed that participants displayed greater limits of stability in water compared to land, possibly indicating a decreased fear of falling.<sup>12</sup> However, older adults were not included in the study, limiting generalizability of the results. Additionally, scientific evidence from studies that compared electromyographic (EMG) responses between environments (water versus land) observed a substantial reduction in lower extremity muscle activity during gait<sup>15,16</sup>, and trunk muscle activity during postural exercises.<sup>17</sup> Data from these studies further question the merit of aquatic balance training and support the need to objectively compare postural sway responses between the two environments, particularly in older adults.

As a consequence, aquatic conditions that optimally challenge balance need to be identified, so that persons who are frequently prescribed aquatic exercise (e.g., elderly with osteoarthritis) may benefit from evidence-based prescriptions. These conditions can be assessed using measures of postural sway (e.g. 95% ellipse area, CoP range, and mean velocity); which have been shown to covary with increased risk of falling in the elderly.<sup>13,18,19</sup>

Manipulating water depth may also challenge balance as this variable possibly influences the magnitude of buoyancy and hydrostatic pressure.<sup>12</sup> Applying water jets (currents) to a person standing may further challenge balance, requiring the patient to activate postural muscles to

equalize forces and remain upright. An appreciation of how these variables influence balance may ultimately lead to more effective aquatic balance training protocols for older and younger adults.

### *1.1. Purpose*

The purpose of this study is to quantify the effect of water immersion and jet perturbation on balance in older and younger adults. It is hypothesized that postural sway measurements will increase with increasing water depth and increasing patient age. It is further hypothesized that the application of water jets will further increase postural sway measurements.

## **2. Methods**

### *2.1. Subjects*

Sixteen older (age =  $62.8 \pm 9.56$  yrs; height =  $1.69 \pm 0.10$  m; weight =  $813 \pm 155$  N) and fifteen younger (age =  $22.5 \pm 1.85$  yrs; height =  $1.72 \pm 0.11$  m; weight =  $735 \pm 184$  N) adults were asked to participate in the study. Participants were recruited from university and community settings and were excluded if they presented any recent lower extremity injury, sensory dysfunction (neural, vestibular, or visual), or a concussion in the 12 weeks prior to the study. Prior to the study, participants were required to sign an informed consent form approved by the Utah State University Institutional Review Board.

### *2.2. Procedure*

Participants attended a single testing session, lasting approximately 40 minutes. Data collection took place in a climate-controlled room in a sports medicine facility. Air temperature and water temperature were regulated to 24°C and 30°C respectively.

During the testing session, participants completed a series of balance trials (double-leg stance, eyes open), each lasting 90 seconds, on a waterproof force platform (Advanced Mechanical Technology, Inc., model OR6-WP, Watertown, MA, USA) under various environmental conditions (Figure 1). Environmental conditions were land and water immersion at the level of the greater trochanter (GT) and xiphoid process (XI). At the xiphoid water depth, participants were perturbed by underwater jets at four intensities: 0% (no jets), 20%, 40%, and 60%. The land trial was completed first, followed by the greater trochanter, and xiphoid water depths. This order was selected to control for shivering and its effect on balance scores. Once participants were at the xiphoid water depth; water jet intensities were randomly assigned to limit possible learning effects during testing.

For each condition, participants were instructed to focus on a white strip of tape placed at eye level about 1.8 m from the edge of the pool (Figure 2). Water-resistant chalk was used to place target marks for the feet on the force platform surface. This was done to insure consistency of foot placement, minimizing variability in base of support geometry across conditions.<sup>20</sup> Participants were given the verbal cue “hands on hips...eyes on the tape...stand as still as possible” immediately prior to triggering the 90 second trial. Studies have shown that the use of this cue may enhance reliability in CoP measurements.<sup>21,22</sup>

All aquatic and land balance trials were performed in the same standing locations. The force platform was positioned on an adjustable floor of an aquatic treadmill (HydroWorx 2000TM, Middletown, PA) with the center of the platform one meter from the edge of the pool (Figure 1 – 2). The force platform and acquisition hardware were calibrated according to manufacturer guidelines.

Participants completed a visual analogue scale (VAS) of perceived stability for all balance conditions. Immediately following each balance trial, participants were asked to make a pen mark on a 117 mm continuous, solid line representing perceived level of stability ranging from “very stable” (0 mm) to “very unstable” (117 mm). This continuum measure was used to provide self-reported perception of balance and thereby serving as a secondary, quantitative assessment of balance between conditions.

### *2.3. Data Analysis*

Static balance assessments via the waterproof force platform were recorded with NetForce data acquisition software and analyzed using BioAnalysis software (AMTI). Force platform data was sampled at 25 Hz. This sampling frequency was chosen since the majority of the CoP displacement signal is contained in low frequencies.<sup>12,23-26</sup> Sample duration of 90 seconds was selected based on previous studies indicating that longer sampling durations increase the possibility of capturing low CoP signal frequencies that otherwise would not be observed with shorter sampling durations (e.g. 15-30 s).<sup>21-23</sup> Medial-lateral (ML) range and anterior-posterior (AP) range of the CoP were chosen as age-sensitive dependent measures since previous studies have observed an increase in AP and ML range in older adults who have experienced falling.<sup>13,18,19,27,28</sup> Ninety-five percent ellipse area ( $\text{cm}^2$ ), and mean velocity ( $\text{cm}\cdot\text{s}^{-1}$ ) of the CoP also served as dependent measures for the balance tests, as these measures are widely used to assess balance by providing information concerning the regulation of postural sway.<sup>12,21,22,28</sup> VAS scores were analyzed by measuring the distance from the left of the scale to the vertical mark drawn by each participant. This distance measure (mm) for each static balance test served as a dependent measure and was used for subsequent statistical analysis.

## 2.4. Statistical Analysis

ML range, AP range, 95% ellipse area, mean velocity, and VAS scores were analyzed using a 2 (age) x 6 (environment) Repeated Measures Analysis of Variance (ANOVA) with age as an independent factor ( $\alpha = 0.05$ ). If significant main effects were revealed pairwise comparisons were obtained for the environment and age factors using a LSD post-hoc assessment. The alpha level was adjusted according to the Bonferroni correction ( $\alpha' = \frac{\alpha}{k}$ ;  $k =$  the number of comparisons). To appreciate the meaningfulness of any significant differences, Cohen's  $d$  effect sizes were computed ( $ES = \frac{\bar{x}_1 - \bar{x}_2}{S_x}$ ; the largest standard deviation ( $S_x$ ) of the two means was chosen).<sup>29</sup>

## 3. Results

### 3.1. ML Range

The ANOVA revealed a significant main effect for environment ( $F = 339, p < 0.001$ ) and age ( $F = 4.77, p = 0.04$ ) factors. There was also a significant environment by age interaction ( $F = 3.26, p = 0.03$ , see Figure 3). Pairwise comparisons for the environment factor revealed the ML range was statistically different across all conditions ( $p < 0.001, ES = 0.72 - 22.0$ , see Table 1). For instance, compared with land values, the ML range for all ages increased 91% and 514% for XI0% and XI60% conditions, respectively. Pairwise comparisons for the age factor revealed the ML range was statistically different between age groups for the GT, xiphoid water depth at 20% jet intensity (XI20%), and xiphoid water depth at 60% jet intensity (XI60%) conditions ( $p = 0.02 - 0.05, ES = 0.61 - 0.80$ , see Table 1). No statistical differences between age groups were revealed for the land, xiphoid water depth at 0% jet intensity (XI0%) and xiphoid water depth at 40% jet intensity (XI40%) conditions ( $p = 0.22 - 0.92, ES = 0.01 - 0.45$ ).

### 3.2. AP Range

Similar to the ML range, a significant main effect for the environment ( $F = 245, p < 0.001$ ) and age ( $F = 13.2, p = 0.001$ ) factors were found for AP range. The results also revealed a significant environment by age interaction ( $F = 16.0, p < 0.001$ , see Figure 3). Pairwise comparisons for the environment factor revealed the AP range was statistically different across all conditions ( $p < 0.001, ES = 0.86 - 16.6$ , see Table 1), except for between the XI0% and XI20% conditions ( $p = 0.06, ES = 0.26$ ). Pairwise comparisons for the age factor revealed the AP range was statistically different between age groups for the XI40% and XI60% conditions ( $p = < 0.001 - 0.002, ES = 1.19 - 1.97$ , see Table 1). No statistical differences were revealed for the land, GT, XI0%, and XI20% conditions ( $p = 0.06 - 0.46, ES = 0.23 - 0.63$ ).

### 3.3. 95% Ellipse Area

Concerning the 95% ellipse area, there was a significant main effect for the environment ( $F = 259, p < 0.001$ ) and age ( $F = 21.9, p < 0.001$ ) factors. The results revealed a significant environment by age interaction ( $F = 27.8, p < 0.001$ , see Figure 3). Pairwise comparisons for the environment factor revealed the 95% ellipse area was statistically different across all conditions ( $p < 0.001, ES = 0.63 - 12.3$ , see Table 1). For instance, compared with land values, the 95% ellipse area increased 253% and 2,858% for the XI0% and XI60% conditions, respectively. Pairwise comparisons for the age factor revealed the 95% ellipse area was statistically different between age groups for the GT, XI40%, and XI60% conditions ( $p = < 0.001 - 0.004, ES = 0.94 - 1.70$ , see Table 1). No statistical differences were revealed between age groups for the land, XI0%, and XI20% conditions ( $p = 0.15 - 0.97, ES = 0.01 - 0.52$ ).

### 3.4. Mean Velocity

Regarding the mean velocity, there was a significant main effect for the environment factor ( $F = 90.5, p < 0.001$ ), but no significant effect was seen for the age factor ( $F = 3.65, p = 0.07$ ). However, results did show a significant environment by age interaction ( $F = 3.93, p = 0.02$ , see Figure 3). Pairwise comparisons for the environment factor revealed the mean velocity was statistically different across all conditions ( $p = < 0.001 - 0.04, ES = 0.98 - 9.12$ , see Table 1), except for between the XI0% and XI20% conditions ( $p = 0.35, ES = 0.07$ ), and between the XI20% and the xiphoid water depth at 40% jet intensity (XI40%) ( $p = 0.07, ES = 0.19$ ). Pairwise comparisons for the age factor revealed the mean velocity was statistically different between age groups for only the XI60% condition ( $p = 0.03, ES = 0.63$ ).

### 3.5. VAS Scale

The VAS scores of perceived stability showed similar trends as compared to previous dependent variables. There was a significant main effect for the environment ( $F = 42.3, p < 0.001$ ) and age ( $F = 6.11, p = 0.02$ ) factors. The results also showed a significant environment by age interaction ( $F = 6.22, p = 0.002$ , see Figure 4). Pairwise comparisons for the environment factor revealed the VAS scores were statistically different across all conditions ( $p = < 0.001 - 0.02, ES = 0.28 - 7.51$ , see Table 1). Pairwise comparisons for the age factor revealed the VAS scores were statistically different between age groups for the XI40% and XI60% conditions ( $p = 0.02 - 0.01, ES = 0.81 - 1.04$ ). No statistical differences were seen for the land, GT, XI0%, and XI20% conditions ( $p = 0.09 - 0.92, ES = 0.03 - 0.67$ ).

## 4. Discussion

The present study examined the effect of water immersion and jet perturbation on measures of balance in older and younger adults. We hypothesized that postural sway would

increase with increasing water depth, water jet intensity, and increasing participant age.

Specific to increasing water depth, results revealed that percent of body weight unloading was similar to that previously reported in the literature for younger adults (GT:  $40.2 \pm 3.94$  %, XI:  $68.6 \pm 2.61$  %).<sup>12</sup> Additionally, there were no significant differences ( $p = 0.20-0.73$ ) between the percent of body weight unloading between younger and older adults (GT:  $39.4 \pm 8.22$  %, XI:  $70.6 \pm 5.50$  %) observed in this study. Results revealed that for younger adults, all CoP measures (e.g. ML range, AP range, 95% ellipse area, mean velocity, and VAS scores) increased with increasing water depth and water jet intensity. CoP measures also increased with increasing water depth and water jet intensity for older adults, however, this increase was statistically less than younger adults at higher jet intensities.

In the present study, ML and AP ranges on land (e.g. 1.79 cm, 3.32 cm, respectively, see Table 1) were consistent with values reported in previous research (e.g. 1.80 cm, 2.50 – 3.20 cm).<sup>30</sup> As expected, there was a greater change in AP range as compared to ML range with increasing water jet intensity. Since water jet perturbations were applied in the sagittal plane, our participants possibly exhibited more sagittal plane postural adjustments (e.g. AP) as compared to frontal plane adjustments (e.g. ML). Additionally, as seen in Figure 5, there are no visual differences in postural strategies between younger and older adults with the application of water jets. Younger adults had a greater maximum anterior displacement than older adults at both the XI40% and XI60% conditions. This mirrors data that revealed greater AP range in younger adults compared to older adults at these conditions. Studies have shown that older adults who typically fall demonstrate a greater amount of AP postural sway, and that significant improvements in AP and ML ranges can be seen following aquatic balance training.<sup>3,13</sup>

Therefore, the application of jet perturbations in both the AP and ML directions may lead to improvements in balance in older adults that are classified as at-risk for falling. Additional research is needed to address this assumption.

Similarly to AP and ML ranges, 95% ellipse area and mean velocity increased as water depth increased, which is consistent with research that examined how static balance was affected when immersed in chest deep water.<sup>12</sup> Descriptively, there are no visual differences across older and younger participants with respect to the ramp-up phase when looking at the 95% ellipse area time series plot (see Figure 6). Although there were no statistical differences observed in mean velocity between the lower water jet intensities (e.g. XI0%, XI20%, and XI40%) there were differences observed between the XI0% and XI60% intensity; suggesting potential increased postural demands at higher water jet intensities as compared to lower intensities. It makes sense that trends in 95% ellipse area mirror those seen in AP and ML ranges, given that all three measures are computed from CoP displacement in the AP and ML directions. Additionally, given the quadratic relationship between increasing jet intensity (predictor) and drag force (response) observed by Bressel et al.<sup>31</sup>, it makes sense that sway measurements mirror this relationship as jet intensity increases (see Figure 3).

An individual's perception of their environment influences postural adjustments<sup>32,33</sup>. This is evidenced by findings from Adkin et al., which revealed that younger participants took longer to make postural corrections as the perceived environmental threat (platform height) increased<sup>33</sup>. Research has shown that young adults experience a decrease in perceived stability (measured by VAS scores) with increasing water depth immersions.<sup>12</sup> Our results revealed that younger and older adults experience this same decrease in perceived stability as water depth

and water jet intensity increases. Additionally, older adults exhibited consistently lower (e.g. very stable) VAS scores at higher jet intensities as compared to their younger counterparts (see Figure 4, Table 1). This difference in perceived stability between younger and older adults could be due to the viscous properties of water, in that older adults possibly experience a reduced fear of falling; conceivably making aquatic environments efficacious for balance training.<sup>7</sup> Moreover, it was observed for all dependent measures (e.g. AP and ML Range, 95% ellipse area, and mean velocity) including VAS scores that there is a significant interaction between environment and age (see, Figure 3 – 4). It is possible that water depth and jet perturbations affect younger and older populations differently. Descriptively, land measures of the 95% ellipse area and AP range (2.59 cm<sup>2</sup>, 3.47 cm, respectively) for older adults were higher than younger adults (2.22 cm<sup>2</sup>, 2.97 cm), consistent with studies that have shown that older adults typically have higher postural sway measurements than younger adults during static balance assessments.<sup>2,5,13,27,28</sup> Conversely, this difference between age groups was not statistically significant. This is consistent with Laughton et al. that revealed no significant differences in postural sway between young, healthy controls, and older, healthy adults, but did reveal significant differences between young, healthy controls and older adults who had experienced a fall.<sup>13</sup> Previous research has provided evidence that in the presence of external perturbations, integrated EMG signals (e.g. tibialis anterior (TA), gastrocnemius (GA), vastus lateralis (VL), and biceps femoris (BF)) of older adults reveal increased duration of postural muscle activation states, later onset latencies, and smaller muscle response amplitudes as compared to younger adults.<sup>34,35</sup> Similarly, older adults typically use a predominate hip strategy versus an ankle strategy to maintain balance, and exhibit proximal muscle activation (e.g. hamstrings,

quadriceps) prior to the distal muscles (e.g. GA, TA) in response to external perturbations.<sup>36</sup> Additionally, studies reveal an increase in postural muscle activation (e.g. TA, VL, BF) during quiet stance in older adults, increasing postural sway measures.<sup>13</sup> That said, studies also reveal a reduction in lower extremity muscle activity (e.g. quadriceps, hamstrings) and trunk muscle activity during dynamic activities within aquatic environments.<sup>16,17</sup> As revealed in our study, older adults exhibited descriptively higher postural sway measures on land as compared to younger adults, assumed to be the result of increased muscle activation. However, during water immersion and jet perturbation (e.g. external perturbation), older adults exhibited lower postural sway scores than younger adults. Therefore, a logical assumption is that upon water immersions, muscle activity in older adults is perhaps brought to more normal levels and therefore more stable postural sway measurements are exhibited, yet, further research is needed to address this assumption.

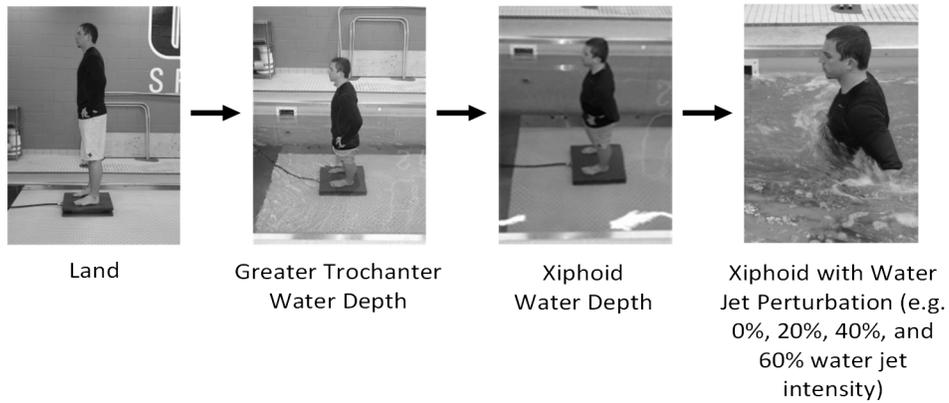
In reference to clinical applications, the added instability of aquatic environments may improve the effectiveness of rehabilitation for special populations (e.g. athletes, elderly) recovering from injury. For example, by using the aforementioned results (e.g. AP and ML range) and previous studies displaying the effectiveness of aquatic therapies<sup>7,10,11,37,38</sup>, clinicians may be better prepared in prescribing aquatic therapies that further challenge balance and improve land based measures as it pertains to falls. Additionally, our observations suggest that therapeutic exercises performed in an aquatic environment are an effective alternative to land-based exercises. Exercises performed in the water are an effective way for clinicians to challenge older adults to a greater extent than similar exercises performed on land. This is evidenced by the decrease in postural sway compared to young, healthy controls observed in

the present study. Additionally, increases in limits of stability seen in younger adults in the aquatic environment support the efficacy of aquatic based therapy for targeting improvements in balance. Therefore, in clinical applications where desired functional outcomes include improvement in postural stability, water immersion to the xiphoid and jet intensities at or above 40% may be more effective than land therapies in stimulating postural sway.

In conclusion, when younger and older adults performed a quiet, double-leg stance task, postural sway measurements increase when the task is performed in water at various depths (e.g. greater trochanter and xiphoid) and with the application of various jet intensities. Future research is needed to better understand the effect of water immersion and jet perturbation on balance measures and to investigate their implementation within rehabilitation prescriptions.

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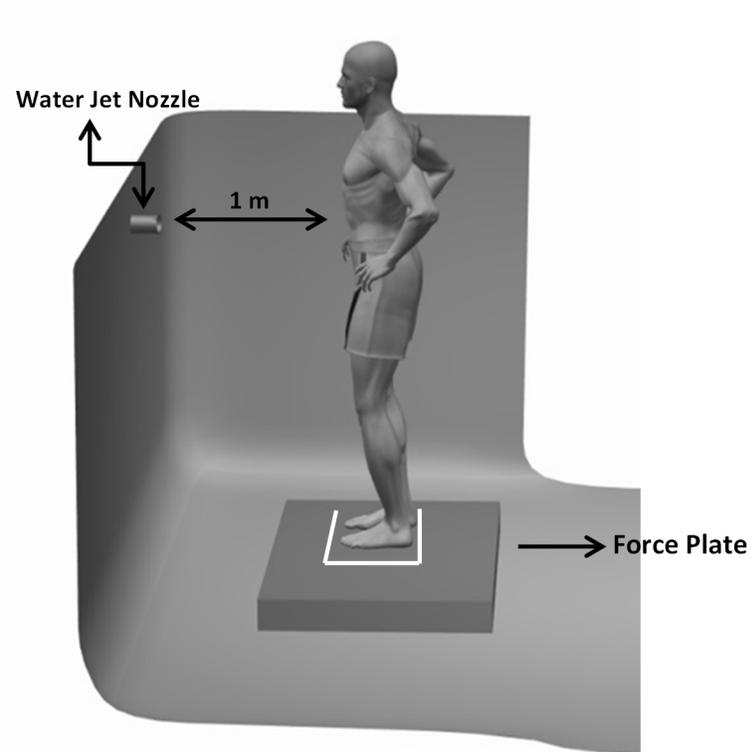
**Figure 1.** Order of data collection for each environmental condition.



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Kinetic data for each environmental condition was acquired in a specific order in order to control for shivering and its effect on balance scores.

**Figure 2.** An illustration of the double leg stance and position of water jets during aquatic conditions.



For all conditions, participants stood with eyes open, hands on hips, 1 meter from the jet nozzle. Participants were instructed to focus on a white strip of tape 1.8 m from edge of pool. Chalk was used to mark feet position as indicated by the white box on the force plate.

**Table 1.** Center of Pressure (CoP) measurements (mean,  $\pm$  SEM) for younger (n = 15) and older (n = 16) participants across land and aquatic conditions.

Measure and Variable		Land	GT	XI0%	XI20%	XI40%	XI60%
ML Range (cm)							
Younger <sup>a</sup>	Mean	1.71	2.55	3.41	4.47	8.16	12.0
	SEM	0.09	0.15	0.22	0.20	0.39	0.48
Older	Mean	1.86	2.03	3.41	3.90	7.49	10.1
	SEM	0.20	0.18	0.18	0.24	0.38	0.60
All Participants <sup>b</sup>	Mean	1.79	2.28	3.41	4.17	7.81	11.0
	SEM	0.11	0.13	0.14	0.16	0.28	0.42
AP Range (cm)							
Younger <sup>a</sup>	Mean	2.97	4.36	6.51	7.26	12.3	16.1
	SEM	0.20	0.25	0.48	0.44	0.69	0.64
Older	Mean	3.48	3.94	6.08	6.17	9.07	11.2
	SEM	0.23	0.19	0.31	0.33	0.60	0.61
All Participants <sup>c</sup>	Mean	3.23	4.14	6.29	6.70	10.6	13.6
	SEM	0.16	0.16	0.28	0.29	0.54	0.62
95% Ellipse Area (cm <sup>2</sup> )							
Younger <sup>a</sup>	Mean	2.22	5.81	8.49	14.1	38.5	94.6
	SEM	0.25	0.68	0.85	1.52	3.51	6.81
Older	Mean	2.59	3.33	8.53	10.8	25.7	49.7
	SEM	0.42	0.32	0.69	1.58	2.46	4.01
All Participants <sup>b</sup>	Mean	2.41	4.53	8.51	12.4	32.0	71.4
	SEM	0.25	0.43	0.53	1.12	2.39	5.60
Mean Velocity (cm*s <sup>-1</sup> )							
Younger	Mean	7.60	12.1	21.7	23.1	25.8	29.9
	SEM	0.53	1.16	1.44	2.01	2.65	3.57
Older	Mean	7.20	9.79	20.5	20.0	20.6	21.2
	SEM	0.44	0.49	0.98	1.17	1.17	1.23
All Participants <sup>d</sup>	Mean	7.39	10.9	21.1	21.5	23.1	25.4
	SEM	0.34	0.64	0.85	1.16	1.47	1.98
Visual Analog Scales (VAS) of Perceived Stability (mm)							
Younger <sup>a</sup>	Mean	9.33	14.9	24.7	34.6	47.5	61.4
	SEM	1.84	2.21	4.20	6.63	6.85	7.85
Older	Mean	9.00	12.5	13.8	18.6	20.0	36.8
	SEM	2.70	2.90	3.03	4.51	4.47	5.80
All Participants <sup>b</sup>	Mean	9.17	13.7	19.5	26.9	34.2	49.5
	SEM	1.58	1.79	2.77	4.27	4.83	5.37

Abbreviations: ML, Medial-lateral; AP, Anterior-posterior; GT, Greater trochanter water depth; XI0%, Xiphoid water depth at 0% jet intensity; XI20%, Xiphoid water depth at 20% jet intensity; XI40%, Xiphoid water depth at 40% jet intensity; XI60%, Xiphoid water depth at 60% jet intensity.

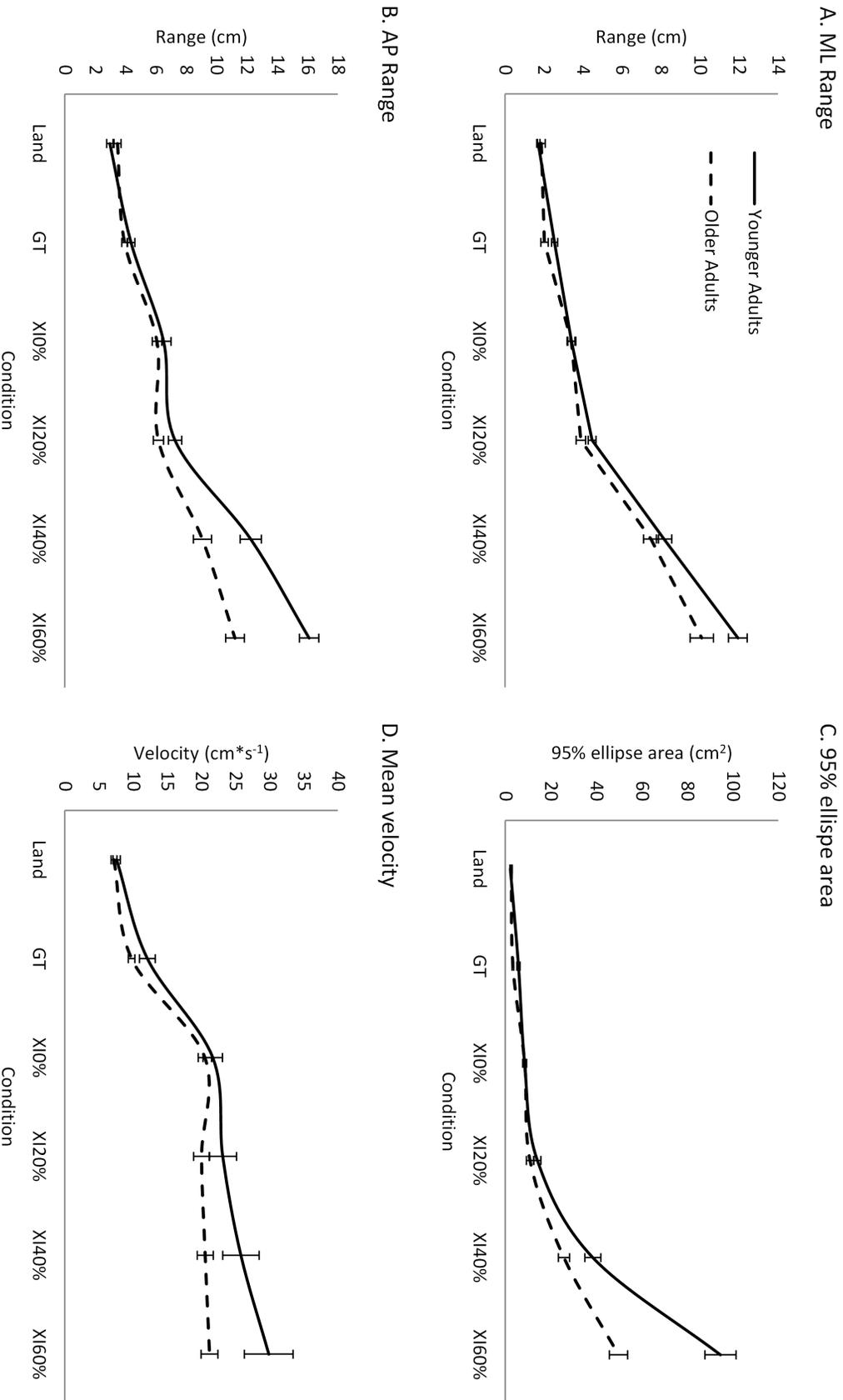
<sup>a</sup> Different between age groups,  $p < 0.05$

<sup>b</sup> Different across all conditions,  $p < 0.05$

<sup>c</sup> Different between all conditions except for between XI0% and XI20%

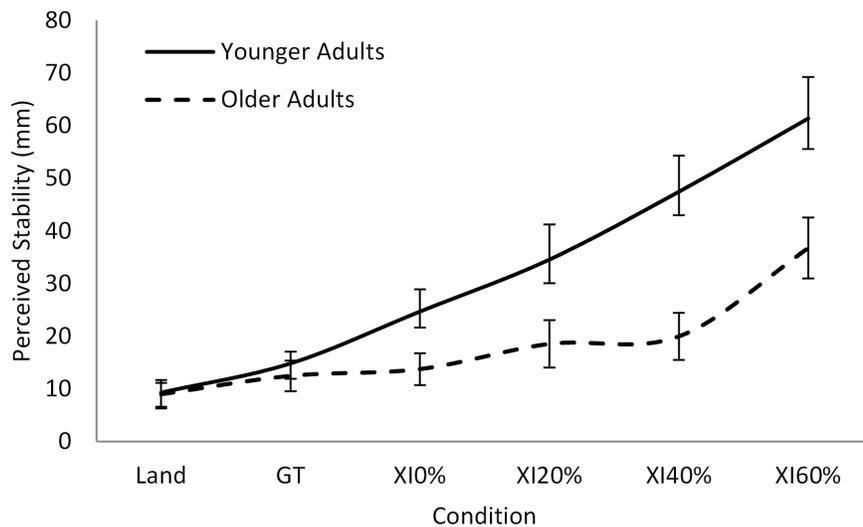
<sup>d</sup> Different between all conditions except for XI0% through XI40%

**Figure 3.** An illustration of the significant ( $p < 0.05$ ) age by center of pressure (COP) interactions for each environmental condition.



Abbreviations: ML, Medial-lateral; AP, Anterior-posterior; GT, Greater trochanter water depth; XI0%, Xiphoid water depth at 0% jet intensity; XI20%, Xiphoid water depth at 20% jet intensity; XI40%, Xiphoid water depth at 40% jet intensity; XI60%, Xiphoid water depth at 60% jet intensity.

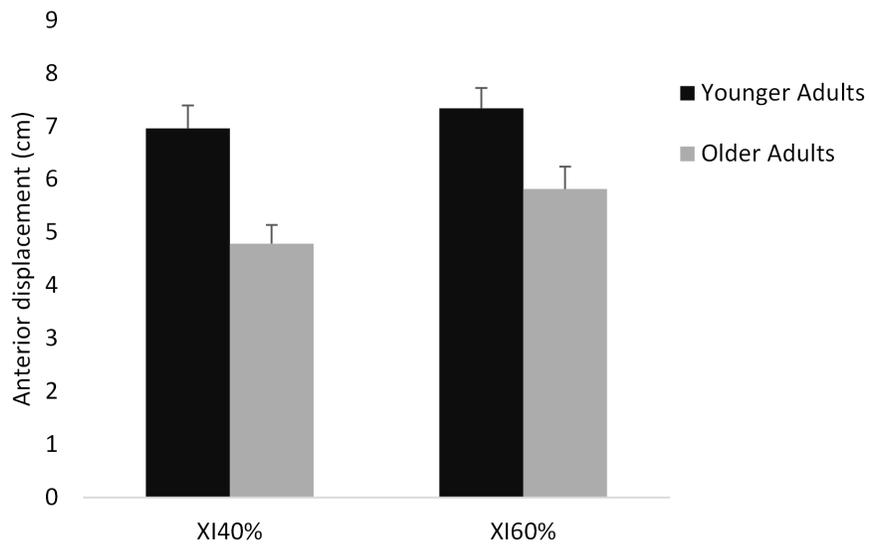
**Figure 4.** An illustration of the significant ( $p < 0.05$ ) age by visual analog scale (VAS) scores for perceived stability interaction for each environmental condition.



Abbreviations: GT, Greater trochanter water depth; X10%, Xiphoid water depth at 0% jet intensity; X120%, Xiphoid water depth at 20% jet intensity; X140%, Xiphoid water depth at 40% jet intensity; X160%, Xiphoid water depth at 60% jet intensity.

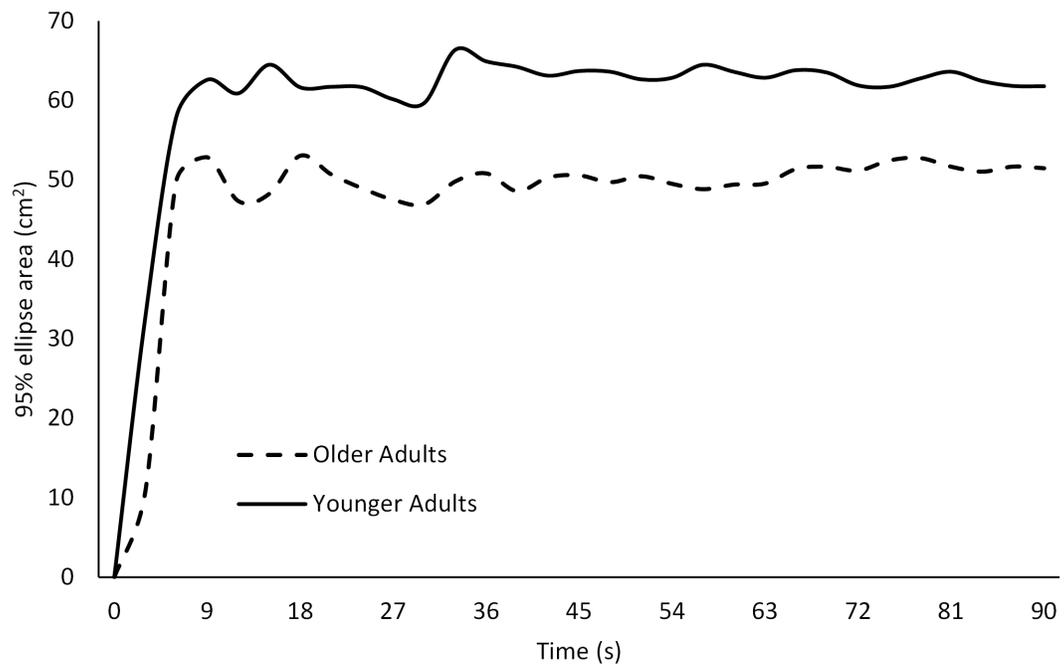
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**Figure 5.** Visual representation of the maximum anterior displacement of the CoP during quiet stance at two different aquatic conditions.



Abbreviations: XI40%, Xiphoid water depth at 40% jet intensity; XI60%, Xiphoid water depth at 60% jet intensity.

**Figure 6.** A visual representation of the typical 95% ellipse area time series at xiphoid water depth at 40% jet intensity.



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