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The influence of the aquatic environment on the control of postural sway

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ABSTRACT

Balance training in the aquatic environment is often used in rehabilitation practice to improve static and dynamic balance. Although aquatic therapy is widely used in clinical practice, we still lack evidence on how immersion in water actually impacts postural control. We examined how postural sway measured using centre of pressure and trunk acceleration parameters are influenced by the aquatic environment along with the effects of visual information. Our results suggest that the aquatic environment increases postural instability, measured by the centre of pressure parameters in the time-domain. The mean velocity and area were more significantly affected when individuals stood with eyes closed in the aquatic environment. In addition, a more forward posture was assumed in water with eyes closed in comparison to standing on land. In water, the low frequencies of sway were more dominant compared to standing on dry land. Trunk acceleration differed in water and dry land only for the larger upper trunk acceleration in mediolateral direction during standing in water. This finding shows that the study participants potentially resorted to using their upper trunk to compensate for postural instability in mediolateral direction. Only the lower trunk seemed to change acceleration pattern in anteroposterior and mediolateral directions when the eyes were closed, and it did so depending on the environment conditions. The increased postural instability and the change in postural control strategies that the aquatic environment offers may be a beneficial stimulus for improving balance control.

1. Introduction

Postural sway during quiet standing has been widely investigated to evaluate the postural stability in the young, elderly [1] and individuals with disabilities [2]. This is because the postural sway allows one to examine interplay of sensory information from visual, vestibular and somatosensory systems, and how they are integrated to generate corrective torques to maintain body equilibrium during quiet standing [3]. Various behavioral studies have been conducted to examine the influence of sensorial input on postural sway during quiet standing by modifying or perturbing one of the sensory modalities or mechanical constraints [4–6].

The aquatic environment has been widely used as a therapeutic modality to improve static and dynamic balance in various patient populations [7,8]. Immersion in water can be considered as a form of sensorial and mechanical perturbation that is applied to the person who is standing in water. In addition, closing eyes while standing in the aquatic environment could potentially lead to further instability as shown in previous studies in a different sensory perturbation scenario [9]. Understanding the underlining mechanisms of immersion in water on postural stability could enable us to develop targeted rehabilitative programs for aquatic environments. However, the influence of immersion on postural sway has been investigated only sporadically, even though it has been speculated for some time that training in the aquatic

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environment may improve postural stability during standing on dry land [8,10].

Two recent studies have reported that center of pressure (COP) parameters were larger in water in comparison to land [11,12]. However, these two studies performed single quiet standing trials for each condition of interest to calculate COP parameters. In Louder's study, the effect of vision was tested only in one trial with eyes open and one trial with eyes closed condition, and the difference observed was not significant. In addition, the order of experiments in two environments was not randomized among participants. To accurately calculate COP parameters and to investigate the effect of vision on postural sway, one needs to perform COP measurements during longer time periods (at least 90 s) and to carry out between 3 and 5 trials for every single experimental condition to obtain reliable COP parameters [13]. Therefore, the first purpose of this study was to investigate the influence of the aquatic environment on COP parameters during quiet standing, using a more robust experimental methodology, i.e. longer trial period (90 s) and with more repetitions for each experimental condition. In addition, the present study randomized the order of tests on land and in water among the participants.

In most therapeutic pools, the height of water is usually at the level of lumbar region. As a result, one can anticipate that the part of the body that is above the water line and the part of the body that is below the water line may have different dynamics. Therefore, the second objective of this study was to investigate the influence of the aquatic environment on acceleration of the trunk, exploring the contribution of the lower and upper trunk movements on postural sway in the aquatic environment. The lower trunk acceleration was previously used to evaluate postural sway in able-bodied subjects and people with Parkinson's disease [14,15]. However, the contribution of the upper trunk acceleration in relation to the lower trunk has been underexplored during postural sway and in particular during quiet standing in water.

Our hypotheses going into this study were the following. First, we hypothesized that the fluctuation of postural sway, measured by COP parameters and trunk acceleration, would be larger in water compared to standing on land. Second, we hypothesized that the ratio of upper trunk to lower trunk acceleration would be significantly higher when individuals were standing in water compared to standing on land, due to the influence of water resistance and body weight offloading on the lower part of the trunk. Third, we hypothesized that visual information (i.e., eyes open and closed conditions) could affect postural sway differently between standing in water and on dry land, since different sensory inputs on the immersed part of the body could increase the demand for visual input while standing in water.

2. Methods

2.1. Participants and location

Ten able-bodied volunteers (6 male and 4 female) without any known history of physical or mental impairments and any contraindication to immersion in thermal water were assessed (Table 1). Prior to enrolling into the study, participants reviewed and signed a written informed consent. Ethical approval was obtained by our institution.

Both tests in water and on dry land were performed at a therapy pool area in our clinical facility (Fig. 1). During tests in water, the level of immersion for all participants was around the umbilicus, and the water temperature was set at 34–35 °C.

2.2. Instrumentation

A waterproof force plate ORP-WP-1000 (AMTI, USA) was used to collect kinetic data, from which we obtained COP in anteroposterior (AP) and mediolateral (ML) directions. A 16-channels data acquisition system Powerlab16/35 (ADInstruments, USA) was used to collect the force plate signals with a sampling frequency of 1000 Hz. Two wireless body-worn inertial sensors (Physilog, GaitUp, Switzerland) sealed in waterproof bags were attached to the lower trunk region (L5/S1) and to the upper trunk region (head of sternum) using medical adhesives. Their 3D-acceleration signals were synchronously collected at a sampling frequency of 500 Hz.

A mechanical switch embedding a force sensitive resistor (FSR) sensor was used to synchronize inertial sensor signals with the force-plate signals. The exact same instrumentation was used in water and on dry land. We carefully controlled the aquatic environment by shutting down the water flow and monitoring the examiner and participant movement in water (Fig. 1).

2.3. Experimental procedure

Participants were requested to stand "as still as possible" with arms crossed in front of their chest and with a comfortable foot position. Feet contour and ankle line were marked with a water-resistant chalk (Fig. 1) on the force plate and kept exactly the same between the environments. A mild mechanical strike was applied on the FSR placed over the trunk inertial sensor to trigger the beginning of each trial. As such, the beginning of each trial was recorded by both FSR (connected to the data acquisition system) and inertial sensors (recording on an internal memory card). We waited approximately 10 s prior to start 100 s of data collection to avoid the potential influence of the mechanical strike on the sway

Table 1
Demographic and anthropometric measures of the participants.

Subject	Gender	Age (years)	Height (cm)	Body weight (N)	Apparent body weight (N)	%Offload
1	F	21	175	625.0	270.0	56.8
2	M	19	173	625.9	309.1	50.6
3	M	18	175	727.2	357.7	50.8
4	F	23	171	627.3	274.1	56.3
5	M	20	179	737.5	362.1	50.9
6	M	24	173	610.4	307.3	49.7
7	M	23	175	794.2	418.3	47.3
8	F	29	165	438.8	182.2	58.5
9	F	21	168	720.9	266.4	63.1
10	M	35	178	753.7	463.2	38.5
Mean	*6 M/4F*	*23*	*173*	*666.1*	*321.0*	*52.2*
SD		*5*	*4*	*103.0*	*81.7*	*6.8*

Note: %offload indicates the percentage of body weight offloading in water calculated as %offload = (BWland − BWwater/BWland) * 100, where BWwater and BWland indicate averages of the vertical force during quiet standing in water and on land, respectively.