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Biomechanical characteristics of adults walking in shallow water and on land

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Abstract

Although water environment has been employed for different physical activities, there is little available information regarding the biomechanical characteristics of walking in shallow water. In the present study, we investigated the kinematics, ground reaction forces (GRF), and electromyographic (EMG) activation patterns of eight selected muscles of adults walking in shallow water and on land. Ten healthy adults were videotaped while walking at self-selected comfortable speeds on land and in water (at the Xiphoid process level). In both conditions there was a force plate embedded in the middle of each walkway to register the GRF components. Reflective markers were placed over main anatomical landmarks and they were digitalized later to obtain stride characteristics and joint angle information. In general, walking in water was different to walking on land in many aspects and these differences were attributed to the drag force, the apparent body weight reduction, and the lower comfortable speed during walking in shallow water. The joint range of motions (ROM) were not different, the segment ROM, magnitudes of GRF components, impact force, and impulse were different between the two conditions. The present results will contribute to a better understanding of this activity in the context of training and rehabilitation.

Keywords: Gait; Physical activity; Ground reaction force; Kinematics; Electromyography

1. Introduction

Lately, the water environment has been employed for different physical activities other than swimming, such as walking and running [2,13,14]. From a mechanical point of view, there are two main reasons for this: the lower apparent body weight due to the buoyant force (the larger the submersed part of the human body, the lower the apparent body weight), and the increased resistance to movement due to the drag force exerted by water on the human body (the larger the frontal area and faster the movement of the body, the larger the resistance to movement). Thus, it seems easier to support the body in water than on land, movements are typically performed slowly in water with a longer time to control them, and the impact forces on the musculoskeletal system are diminished.

Even though walking in water has been an effective way of practicing such activities as both training and rehabilitation [13,14], there are few empirical data about their effectiveness. A biomechanical characterization of walking in shallow water could be helpful for a better understanding, for example, of the mechanical loads on the human body, on how humans behave and adapt to such a different environment, and consequently, to contribute to a more appropriate prescription of walking in water as part of training and rehabilitation programs.

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So far, few studies have been conducted to describe some aspects of walking in water and none of these studies provided a full description of the gait characteristics of a complete gait cycle [4,8–11]. Therefore, the purpose of this study was to qualitatively and quantitatively characterize a complete gait cycle of adults walking in shallow water and compare this to them walking on land. Specifically, we analyzed temporal and spatial gait parameters, kinetics (vertical and anterior–posterior ground reaction force components), kinematics (joint and segmental angles), and electromyographic activation patterns of selected muscles.

2. Methods

Ten healthy adults (4 males, 6 females) without any known physical or mental illnesses volunteered for this study. The participants' mean age, height, and mass (± 1 standard deviation) were 29 ± 6 years, 1.65 ± 0.10 m, and 63 ± 10 kg, respectively. Before their participation, they signed an informed consent form that was approved by the local ethics committee of the University of São Paulo.

The participants walked at self-selected comfortable speeds on ten occasions in bare feet, first on a walkway in the laboratory (land condition), and on ten occasions, on a walkway in the swimming pool (water condition). In the water condition, the participants kept their arms on the water surface. The walkway in the swimming pool was set according to the participants' height in such a way that they all walked with the water at the Xiphoid process level (Fig. 1). The experimental setup was designed to perform a bi-dimensional gait analysis of one stride, which consisted of the event between two successive right foot contacts to the ground per trial of the participants' walking. In addition, calibration trials were acquired, during which participants were requested to stand upright on the force plate for 30 s in both conditions.

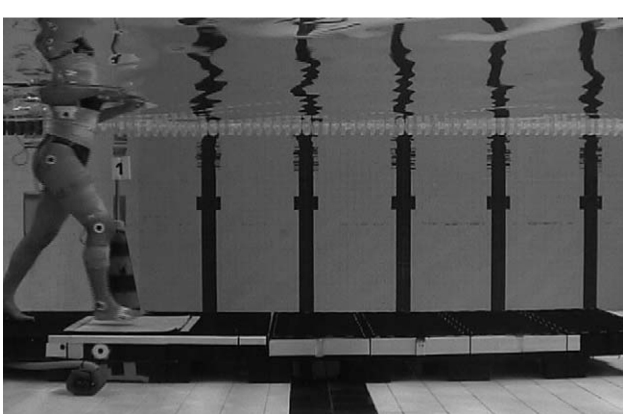

Fig. 1. Partial view of a participant walking in water condition with the water at the Xiphoid process level.

The participants' movement on the sagittal plane (the main plane of movement) was recorded at 60 Hz with digital cameras (GRDVL-9800U, JVC), and one was enclosed in a waterproof housing (#6010.90, Ikelite), in order to obtain kinematic measurements. Passive reflective markers were placed on the participants' right side of the following bony landmarks: fifth metatarsal head, lateral malleolus, femoral epicondyle, greater trochanter, and 5 cm below the lateral projection of the Xiphoid process. The digitalization of all markers was performed using the Ariel Performance Analysis System (APAS) software (Ariel Dynamics, Inc.) and the reconstruction, filtering, and posterior analyses were performed using the Matlab software (Mathworks, Inc., version 6.5). The reconstruction of the real coordinates was performed using the direct linear transformation (DLT) procedure on land, and using a localized two-dimensional DLT procedure in water to account for refraction in the underwater video [7].

We registered the surface electromyographic activity (EMG) from eight muscles on the body's right side: tibialis anterior (TA), gastrocnemius medialis (GM), vastus lateralis (VL), long and short head of the biceps femoris (BFLH and BFSH, respectively), tensor fasciae latae (TFL), rectus-abdominis (RA), and erector spinae (ES) at the first lumbar vertebrae (L1 level) during the task. For such, we used passive disposable dual Ag/AgCl snap electrodes with a 1 cm diameter of each circular conductive area and a 2-cm center-to-center spacing (dual electrode #272, Noraxon). The electrodes were placed on the belly of each muscle along the muscle fiber direction after the skin area was shaved and cleansed with gauze soaked in alcohol. Extreme care was necessary to insulate electrodes for the water condition trials. For this, we used transparent dressing (Tegaderm, 3 M) placed over the electrode and the cable connection near the electrodes. The body segments near by the electrode areas and cables were slightly bandaged with elastic bands to avoid cable movement. The EMG signals were registered with an 8-channel telemetric EMG system (Telemyo 900, Noraxon), which had a gain of 1000 times, bandwidth (-3 dB) of 10–500 Hz, and common mode rejection ratio >85 dB.

We recorded the vertical and the anterior–posterior components of the ground reaction force (GRF) using force plates (OR6-2000, AMTI, on land, and a waterproof OR6-WP-1000, AMTI, in water). GRF and EMG signals were sampled at 1000 Hz using the APAS software and these signals were synchronized to the video images by a homemade trigger.

2.1. Data analysis

All data analyses were performed using the Matlab software. All the data were digitally filtered using a 4th order and zero-lag Butterworth filter. Kinematics data