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# Reliability of ground reaction forces in the aquatic environment

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ABSTRACT

The aim of this study was to verify the reliability of the kinetic parameters of gait using an underwater force platform. A total of 49 healthy participants with a median age of 21 years were included. The kinetic gait data were collected using a 0.6 × 0.6 × 0.1 m aquatic force plate (Bertec®), set in a pool (15 × 13 × 1.30 m) with a water depth of 1.20 m and water temperature of 32.5 °C. Participants walked 10 m before reaching the platform, which was fixed to the ground. Participants were instructed to step onto the platform with their preferred limb and data from three valid attempts were used to calculate the average values. A 48-h interval between tests was used for the test–retest reliability. Data were analyzed using interclass correlation coefficients (ICC) and results demonstrated that reliability ranged from poor to excellent, with ICC scores of between 0.24 and 0.87 and mean differences between $(\bar{d}) = -0.01$ and 0.002. The highest reliability values were found for the vertical (Fz) and the lowest for the mediolateral components (Fy). In conclusion, the force platform is reliable for assessing the vertical and anteroposterior components of power production rates in water, however, caution should be applied when using this instrument to evaluate the mediolateral component in this environment.

## 1. Introduction

Bipedal gait is a skilled and complex activity that requires coordinated and controlled movements of the limbs, which act alternately from one support position to another. Gait can be studied and evaluated in various ways, one of which is through the use of force plates (FPs) that measure the direction and magnitude of the ground reaction forces (GRFs) (Duarte and Freitas, 2010). GRFs are of equal magnitude and the opposite direction to the force the body exerts on the ground through the foot, and must be overcome during forward movement (Sutherland, 2005).

Aquatic exercises are widely used in the treatment of patients with many different medical conditions; these exercises maximize the properties of water related to fluid mechanics, such as viscosity, drag force, turbulent flow and buoyancy to achieve best outcomes for patients. Water is an ideal environment for exercise due to the decreased weight bearing through the lower limbs, offering less impact throughout the stance phase of the gait, but exercise in water also requires greater propulsive force to overcome the force of water (Harrison and Bulstrode, 1987; Nakazawa et al., 1994; Barela et al., 2006). The magnitude of the gait GRFs although lower than on land, can still be excessive, depending on the individual patient and their condition or medical problem. Knowing the GRFs related to different underwater activities during rehabilitation would help in exercise prescription and the evaluation of patients in this environment (Haupenthal et al., 2010c).

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In 1992, Harrison et al. investigated GRFs in the aquatic environment. The authors designed a waterproof FP using a silicon rubber compound to measure weight-bearing during underwater gait at two heights of water submersion (1.1 and 1.3 m) and patients walked at two different speeds (slow and fast). The authors found that the percentage of weight bearing decreases inversely proportional to the speed. Since this seminal work, several other studies have explored GRFs in water during different activities such as running, jumping, backward walking and stationary running, factors such as depth of immersion and gait velocity have also been considered (Haupenthal et al., 2010a; Haupenthal et al., 2010b; Orselli and Duarte, 2011; Fontana et al., 2011, 2012; Donoghue et al., 2011; Carneiro et al., 2012; Haupenthal et al., 2013; Miyoshi et al., 2003).

The use of reliable methods to determine the outcome of clinical interventions is essential as outcomes (or lack of outcomes) can have serious implications for patients. Visual and observational assessment methods are subjective and may not accurately reflect the results of treatment intervention. Thus, reliability studies are needed to evaluate the error in any outcome measure and test–retest studies are required to determine how well any measure performs at different times (Rankin and Stokes, 1998). Such studies may provide data about consistency as well demonstrating the safe use of the outcome measure not only in clinical practice but also in biomechanics research (Portney and Watkins, 2000; Lexell and Downham, 2005).

Several studies have evaluated the reliability of the FP during gait on land in different conditions and with different populations (Kadaba et al., 1989; Hamill and McNiven, 1990; White et al., 1999; Fortin et al., 2008; Veilleux et al., 2012). However, to date there are no studies assessing the reliability of the FP in underwater walking. This is a major gap in the literature considering the extent to which aquatic exercises are used in rehabilitation and the need for a reliable outcome measure. The immersed body is affected by the action of fluid mechanics, which of course influences gait, thus establishing the reliability of kinetic parameters of underwater gait is necessary. The aim of this study therefore was to investigate the test–retest reliability of the kinetic gait parameters, as measured by a FP, in healthy individuals in water.

## 2. Method

### 2.1. Participants

Forty-nine healthy young volunteers participated in this study, 31 females and 18 males, with a median (Md (25–75%)) age of 21 years (20–22), mass of 57.5 kg (53–68), weight in the water of 147 N (98–225.5) and height of 1.65 m (1.60–1.72). The volunteers were considered eligible if they were between 18 and 24 years and had no current lower extremity musculoskeletal pain and/or injury or any disorder affecting sensation in the lower extremity that may affect gait. Volunteers who did not meet these inclusion criteria were excluded. All participants were notified of the procedures and requirements and were invited to participate by signing an informed consent form. The study and all procedures were approved by the Ethics Committee of the UEL (#217/2012).

### 2.2. Instrumentation

Data were collected using a waterproof force platform (Bertec Corporation®, model FP4060-08-2000), with dimensions of 0.6 × 0.6 × 0.1 m, sample rate of the acquisition system of 1000 Hz, capacity of Fz = 5000 N and Fx = Fy = 2500 N and 340 Hz (Fz) and 550 (Fx = Fy) of natural frequency with a 16-bit A/D converter. The FP was placed in the final third of a 10 m pool, located in the Aquatic Physical Therapy Center "Prof. Paulo A. Seibert", with dimensions of 15 × 13 × 1.30 m, extent of submersion around 1.20 m and water temperature of 32.5 °C.

### 2.3. Procedure

The individuals walked on the platform at a self-selected speed, and were asked to walk onto it with their preferred leg. The test was repeated three times or until three valid data recordings had been collected. A trial was considered successful when only one foot made contact with the platform (Fig. 1); trials not meeting these criteria were excluded and another trial was performed. Participants were instructed to walk normally while looking straight ahead and not to look at the platform.

Before starting data collection, participants practiced walking across the platform until they were comfortable with the procedure. The gait cycle started with initial foot contact with the force platform and ended when this foot left the platform. For the test–retest reliability, two recordings were performed with a 48-h interval between them.

### 2.4. Data processing

Force plate data were analyzed using a specific routine in Matlab® 7.9.0 (R2009b, Mathworks, TM), smoothed by a Butterworth low-pass filter of 4th order and cutoff frequency of 5 Hz defined by spectral analysis (Carneiro et al., 2012; Haupenthal et al., 2010b; Miyoshi et al., 2004).

The analyzed GRF components were the vertical (Fz), anteroposterior (Fx) and mediolateral (Fy). Maximum and minimum values were selected from the curve profiles to assess the reliability of gait parameters. For the Fz component, the first peak is the response to load (Fz1), the second point is the valley and represents the average support (valley) and the second peak represents the terminal support (Fz2) (White et al., 1999). For the Fx component, the point selected represents the phase-end or maximum propulsion. Two points were considered for the Fy component, the first peak (Fy1) represents a lateral thrust during loading, during which time the foot is moving from a supinated position into pronation and the second peak (Fy2) is a small lateral force often seen during the final push off stage (these parameters are demonstrated in Fig. 2) (Miyoshi et al., 2004; Richards, 2008). Furthermore, the acceptance rates (AR) which correspond to the curve slope during the loading phase were analyzed, calculated by dividing the value of the response to load by the difference between the beginning and the force peak (Fz1/Δt), as well the propelling

**Fig. 1.** Underwater force platform during data collection.