Gait & Posture 57 (2017) 102–108

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Comparison in three dimensional gait kinematics between young and older adults on land and in shallow water

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ARTICLE INFO

Keywords:
Joint kinematics
Local coordinate system
Ageing
Drag
Buoyancy

ABSTRACT

This study investigated in three-dimensional space, firstly whether the aquatic medium and secondly ageing, had any effect on the lower limb's joint angles during aquatic-based gait. Three-dimensional joint kinematics of the lower limb of 51 healthy male participants [25 young group (24.6 ± 4.9 years, 172.1 ± 5.5 cm, 69.8 ± 10.3 kg) and 26 older group (58.5 ± 5.1 years, 167.9 ± 5.1 cm, 70.8 ± 12.1 kg)] were quantified during land and shallow water walking. Participants walked at their self-selected comfortable speed in both mediums. The results suggested that the properties of water – hydrodynamic drag, and buoyancy – affected the gait kinematics for both groups. Both age groups used more of their hip flexion in the aquatic environment to help them propel forward instead of using the ankle plantarflexion. The effect of age during the aquatic-based gait was identified in ankle adduction angle and knee abduction/adduction angle at initial contact. Only the older group elicited a significantly smaller ankle adduction angle during the aquatic-based gait when compared to the land-based gait. Only the young group elicited a significantly larger knee abduction/adduction angle at initial contact during the aquatic-based gait when compared to the land-based gait. These findings can facilitate professionals in the area of aquatic rehabilitation to better customise aquatic-based walking exercise programmes to suit their client's specific needs.

1. Introduction

Aquatic therapy has been growing in popularity in recent years especially among older adults who have been diagnosed with lower limb injuries or suffering from osteoarthritis due to the supportive nature of water [1]. The aquatic medium provides buoyancy in water that is negligible on land, which acts to reduce the overall body weight acting on the lower limbs that are submerged in water. The impact forces experienced on the foot during a heel strike in an aquatic medium are lower than those on land [2–4]. In addition, the presence of resistive drag in water slows down joint movements and increases the time to activate and execute the neuromuscular control of the limbs to recover from any loss of dynamic balance [5,6].

Aquatic therapy has also gained popularity with a younger group of people including athletes as a form of physical rehabilitation to address lower limb injuries [7] as well as a form of resistance training to improve strength [8,9]. Aquatic exercises prescribed to older adults are usually different from the younger group as age-related diseases such as knee osteoarthritis are not usually symptomatic till the age of 50 [10]. Studies investigating the effects of age on land-based gait highlighted that ageing affects the muscle strength, neuromuscular control, reaction timing and balance of an individual [11–13]. These studies also highlighted the kinematic differences in the land-based gait between the two age groups. We are aware of only one recent study that investigated the kinematic differences of gait between two age groups, and on land and in water [3]. They reported significant differences in joint angles of the knee and ankle during the initial contact between the two age groups when walking in water. Their study, however, limited their investigation to the sagittal plane. Thus, it is probable that there could be significant differences in joint kinematics in three-dimensional space between the two age groups. Such differences would be important information for practitioners who prescribe aquatic-based walking exercises, to differentiate whether the observed changes in gait are due to age, the differences in the medium (land versus water) or due to any other reasons such as effect of injury, surgery or fatigue. Knowing these differences allows better customisation of aquatic-based walking exercise programmes. Thus, the aim of this study was to investigate the effect of firstly the aquatic medium and secondly ageing on the lower limb's joint angles during aquatic-based gait in three-dimensional space.

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http://dx.doi.org/10.1016/j.gaitpost.2017.05.021
Received 20 July 2016; Received in revised form 16 May 2017; Accepted 19 May 2017
0966-6362/

Nomenclature

$Hip_{adduction}$ hip adduction
$Hip_{abduction}$ hip abduction
$Hip_{ext\_rotation}$ hip external rotation
$Hip_{flexion}$ hip flexion
$Knee_{adduction}$ knee adduction
$Knee_{abduction}$ knee abduction
$Knee_{ext\_rotation}$ knee external rotation
$Knee_{flexion}$ knee flexion
$Ankle_{inversion}$ ankle inversion
$Ankle_{adduction}$ ankle adduction
$Ankle_{abduction}$ ankle abduction
$Ankle_{dorsi}$ ankle dorsiflexion
$Ankle_{plantar}$ ankle plantarflexion
Hip_{abd/add_IC} hip abduction/adduction at initial contact
$Hip_{ext/int\_rotation\_IC}$ hip external/internal rotation at initial contact
$Hip_{ext/flex\_IC}$ hip extension/flexion at initial contact
$Knee_{abd/add\_IC}$ knee abduction/adduction at initial contact
$Knee_{ext/int\_rotation\_IC}$ knee external/internal rotation at initial contact
$Knee_{ext/flex\_IC}$ knee extension/flexion at initial contact
$Ankle_{ever/inv\_IC}$ ankle eversion/inversion at initial contact
$Ankle_{abd/add\_IC}$ ankle abduction/adduction at initial contact
$Ankle_{plan/dorsi\_IC}$ ankle plantarflexion/dorsiflexion at initial contact

2. Materials and methods

2.1. Participants

Fifty-one healthy male adults (Table 1) with no history of lower extremity injury within the last six months, participated in this study. Ethical approval and informed consent were obtained prior to the commencement of the study.

2.2. Data collection

The land-based gait trials were conducted in the Biomechanical Laboratory and the aquatic-based gait trials were conducted in a swimming pool (18 m long × 16 m wide × 1.2 m deep). Sixteen retro-reflective markers were secured on the bony landmarks of the participants, namely: the right and left anterior and the posterior superior iliac spine (ASIS and PSIS), medial and lateral femoral epicondyles, medial and lateral malleoli, calcaneus and the head of the second metatarsal of the foot.

After the familiarisation trials, the participants walked barefooted in a forward direction for 5 trials at self-selected speed over a 15 m distance on a dry floor surface for the land condition, and over a 12 m distance in the swimming pool for the water condition. For the land condition, kinematic data were acquired at 100 Hz using 12 Motion Analysis Corporation Eagle 4 cameras (Santa Rosa, CA, USA). For the water condition, kinematic data were acquired at 100 Hz using 8 Oqus Underwater cameras (Qualisys, Göteborg, Sweden). The instruction was given to look forward during walking in both conditions and to keep both their elbows flexed such that their forearms floated on the surface of the water in the water condition. Both conditions allowed the participants to have sufficient rest between each trial to avoid any effects of fatigue.

2.3. Data reduction

Initial contact (IC) and toe-off (TO) were estimated from the respective marker positions of the calcaneus and the second metatarsal using the Foot Velocity Algorithm [14]. Trajectory data of a single gait cycle were filtered using a fourth-order zero-lag low-pass Butterworth filter with a 11 ± 5 Hz cut-off frequency [15]. These filtered data were used to estimate the hip joint centre [16]. The kinematic calculations from these post-processed trajectory files were accomplished using Visual3D™ (v3.89, C-Motion Inc., Rockville, MD, USA). Hip, knee and ankle joint angles in the three-dimensional space were computed based on the joint coordinated system [17]. At each joint, the rotation of the distal segment was described with respect to a fixed proximal segment. After normalising each trial data with time, the kinematic data of the 5 trials were used to obtain the averaged single representative trial. Although gait symmetry has been debated [18], this study used the averaged angle, obtained from both the right and left lower limb's joint angles to simplify the comparison in the different conditions as well as age groups [19].

This study compared the maximum angles of the hip, knee and ankle joints and their respective angles at IC within one complete gait cycle of each representative trial between land and water conditions. The maximum joint angle, which can be used to calculate the range of motion of each joint, varies based on the maximum degree of rotation about a specific axis such that the maximum value indicates how the range of motion varies during the aquatic-based gait compared with the land-based gait. The first peak of the ground reaction force, which may relate to lower limb injury [20], is usually observed just after IC during land-based gait and is reduced during aquatic-based gait [3]. Thus, differences in the joint angles at IC during the aquatic-based gait were expected and would be associated with the effect of hydrostatic and hydrodynamic forces on the joint angles.

To validate the repeatability of the 5 trials, the average and standard deviation within participant (SD_{within}) of the walking speed for each participant were calculated and the ratio of SD_{within} to the average of the walking speed was then computed. The walking speed was determined by the average position of both right and left ASISs and PSISs.

2.4. Statistical analysis

All kinematic results were submitted to a two-way mixed design ANOVA (SPSS PASW 18.0, Chicago, IL, USA) to test for the main effects of conditions (land versus water) and age groups (young versus older), and interactions effects between the conditions and the age groups with the conditions treated as repeated measure in each participant. The independent variables were the conditions and the age groups. The dependent variables were the maximum angles of hip, knee and ankle joints and their respective angles at IC. A separate simple effects analysis was performed as a post hoc test on the significant interaction effects using pairwise comparison adjusted with the Bonferroni correction. A paired t-test was used to compare the walking speed between the different conditions for each group and an unpaired t-test was used to compare the walking speed between the different age groups for each condition. All data were analysed at the level of $\alpha = 0.05$ for the main and interaction effects and at $\alpha = 0.0125$ for the post hoc test.

3. Results

For both conditions, the walking speeds for the young group were not significantly different from those for the older group (water:

Table 1
Profile of participants (mean and standard deviations).

	Young	Older
Number of participants	25	26
Age (yrs)	24.6 ± 4.9	58.5 ± 5.1
Height (cm)	172.1 ± 5.5	167.9 ± 5.1
Mass (kg)	69.8 ± 10.3	70.8 ± 12.1