The influence of the aquatic environment on the center of pressure, impulses and upper and lower trunk accelerations during gait initiation

Running title: The influence of the aquatic environment on gait initiation

Authors:

Andresa R. Marinho-Buzelli[a,b], Kei Masani[b,c], Hossein Rouhani[d], Ana M. Barela[e], Gustavo T.B. Fernandes[f], Mary C. Verrier[a,b,g], Milos R. Popovic[a,b,c]

Affiliations:

a. Rehabilitation Sciences Institute, University of Toronto, Toronto, Canada

500 University Avenue, Toronto, ON, Canada, M5G 1V7

b. Toronto Rehabilitation Institute – University Health Network, Toronto, Canada

Lyndhurst Centre

Toronto Rehabilitation Institute - University Health Network

520 Sutherland Drive, Toronto, ON, M4G 3V9, Canada

c. Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Canada

164 College Street, Room 407, Toronto, Ontario, M5S 3G9, Canada

d. Department of Mechanical Engineering, University of Alberta, Edmonton, Canada

Donadeo Innovation Centre for Engineering, 9211-116 Street NW, Room 10-368, Edmonton, AB, Canada, T6G 1H9

e. Institute of Physical Activity and Sport Sciences, Cruzeiro do Sul University, Sao Paulo, Brazil

Rua Galvão Bueno, 868, 13o. andar, Bloco B, Liberdade, Sao Paulo, SP, Brazil, 01506-000

f. Department of Mechanical Engineering, Federal University of Santa Catarina, Santa Catarina, Brazil

Caixa Postal 476 - Campus Universitário – Trindade, 88040-900, Florianópolis, SC, Brazil

g. Department of Physical Therapy, University of Toronto, Toronto, Canada

500 University Avenue, Toronto, ON, Canada, M5G 1V7

Emails:

Andresa R. Marinho-Buzelli: andresa.marinho@mail.utoronto.ca

Hossein Rouhani: hrouhani@ualberta.ca

Ana M. Barela: ana.barela@cruzeirodosul.edu.br

Gustavo T.B. Fernandes: gustavo.tbf@hotmail.com

Mary C. Verrier: m.verrier@utoronto.ca

Milos Popovic: milos.popovic@utoronto.ca

Corresponding Author:

Kei Masani

Rehabilitation Engineering Laboratory, Lyndhurst Centre

Toronto Rehabilitation Institute – University Health Network

520 Sutherland Drive, Toronto, M4G 3V9, Ontario, Canada

Phone: +1-416-597-3422 ext 6098

Fax: +1-416-425-9923

E-mail: k.masani@utoronto.ca

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Abstract

Gait initiation is defined as the transition from stationary standing to steady-state walking. Despite the frequent use of therapy pools for training walking in early stages of rehabilitation, none have been reported on the effects of immersion on gait initiation. We aimed to analyze the center of pressure (COP) trajectories, the vertical and anteroposterior impulses and upper and lower trunk accelerations during anticipatory (APA) and execution phases of gait initiation. In the COP trajectory, the execution (EXE) phase was further subdivided in two phases: predominantly mediolateral (EXE1), and predominantly anteroposterior (EXE2). Able-bodied participants initiated gait while standing on a force plate and walked approximately 4 steps following a visual cue. The participants were wearing three inertial sensors placed on the lower and upper trunk, and on the stance shank. Individuals performed 10 trials each on land and in water, in two consecutive days. The lengths and velocities of COP trajectories increased in water compared to land during APA, while the COP length increased and the COP velocity reduced in water during EXE2. The anteroposterior impulses increased in water during EXE. Lower trunk acceleration was smaller in water while the upper trunk acceleration did not differ, resulting in the larger ratio of upper to lower trunk acceleration in water during EXE. Overall, immersion in water increases COP length during gait initiation, and reduces COP velocity during EXE2, indicating a new postural strategy in water. The aquatic medium may be favorable for individuals who need weight support, gradual resistance and a longer time to execute gait initiation.

Keywords*:* aquatic environment; gait initiation; anticipatory postural adjustment; center of pressure; trunk acceleration

Introduction

Gait initiation is a common functional task defined as the transition from stationary standing to steady-state walking[1]. Gait initiation is frequently divided in two phases, the anticipatory postural adjustment (APA) phase and the execution of the first step[2][3][4]. The APA phase is known to generate the forward momentum[3] and to control the mediolateral (ML) stability[2] for the execution of the first step (EXE).

Effects of various sensorimotor and environmental conditions, such as with different speeds[2], different step lengths[5], stepping over obstacles[6], and changing initial stance position[7], on gait initiation have been investigated. However, to date, gait initiation has been underexplored in the aquatic environment, even though gait training in the aquatic environment is a common and effective approach for rehabilitation in people with various gait and balance impairments[8]. The physical properties of water appear to benefit people with low-functioning performance by providing body offloading due to buoyancy and moderate resistance due to water viscosity[9][10].

In our previous study[11], we demonstrated that the aquatic environment affects the center of pressure (COP) trajectory, the impulse exerted by the body, and kinematics of lower limbs during gait initiation. However, as only the lower body segment receives resistance due to water viscosity and the upper body segment is left to move freely, the relation of movements between upper and lower body segments in water can be different from that on the land. Thus, in the current study, we investigated the relation of movements between upper and lower body segments in addition to the COP trajectory and impulses.

Further, in the current study, we propose to divide the EXE phase into two phases to differentiate two events on the execution phase of the COP, i.e., in one the COP predominantly moves in ML direction (EXE1) and in the other the COP predominantly moves in anteroposterior (AP) direction (EXE2). In this way, we were able to identify the trajectory that corresponds to the weight-transferring to the stance limb (the ML COP trajectory, EXE1) and one corresponding to stepping forward (the AP COP trajectory, EXE2). The aquatic medium may affect these COP trajectories differently in AP and ML directions due to the effects of water resistance and buoyancy when body moves during weight transfer and stepping forward in water. Under the support of buoyancy, the ML COP trajectory in EXE1 would increase due to a longer weight transfer and the AP trajectory during EXE2 would increase because individuals could take a longer first step or lean more forward. In other words, we hypothesize that the EXE1 trajectory would be predominantly longer in ML direction and EXE2 trajectory would be predominantly longer in AP direction. Furthermore, the water resistance would increase the duration of the trajectories as the COP velocity during EXE2 would decrease.

Therefore, the aim of the present study was to investigate the kinematics and kinetics of posture during gait initiation in water, focusing on trunk acceleration and with newly proposed divisions of COP. We first hypothesized that the aquatic medium would increase the length of COP trajectory during APA and execution phases, and would decrease velocity while individuals are stepping forward. Second, we hypothesized that a greater mean AP force would be required during the first step, in order to overcome water resistance. Third, we hypothesized that the ratio between upper and lower trunk accelerations in AP direction would increase (acceleration of upper trunk > acceleration of lower trunk) in water during execution phase compared to on land walking, due to greater resistance that the lower trunk and legs experience in water.

Methods

Participants and location

Ten able-bodied volunteers (5 females, age 19-35 years, weight 46-81 kg, height 164-178 cm, and body mass index 17-26), without contraindication to immersion in thermal water, participated in this study. Participants reviewed and signed a written informed consent. Ethical approval was obtained.

Tests in water and on dry land were conducted in the hydrotherapy pool area. The water temperature was set around 35°C. Tests on dry land were performed at the pool side in order to avoid any environmental difference other than immersion in water.

Instrumentation

A 9.80mx4.90mx1.10m therapy pool was used for the water experimental condition. The water flow/pump of the pool was turned off to minimize water turbulence. In both environments, we used an aluminum custom-made walking pathway (2.80mx0.51mX0.08m). A waterproof force plate (ORP-WP-1000, AMTI, USA) was placed in level with the aluminum pathway to align both surfaces. The force plate recorded ground reaction force (GRF) components and moments at a sampling frequency of 1000Hz.

Three wireless body-worn inertial sensors (Physilog, GaitUp, Switzerland) sealed in waterproof bags were firmly attached to the lower trunk region (L5/S1 vertebrae), upper trunk region (head of sternum) and on the shank of first stance limb using waterproof medical adhesives. Each inertial sensor contained a 3D-accelerometer and a 3Dgyroscope. The accelerometer had a range of ±11*g* for each of three directions. The inertial sensors recorded data synchronously on memory cards at a sampling frequency of 500Hz.

We analyzed data from the trunk inertial sensors synchronized by means of a mechanical strike applied on a waterproof force sensitive resistor switch placed over the upper trunk inertial sensor, before and after each trial. This strike was used for synchronization of the force plate and the inertial sensor data *a posteriori*.

Experimental Procedure

A feet contour was drawn on the force plate on land in comfortable position one day prior to the gait initiation experiment to assure the same standing position between both conditions. We also determined the preferred leg for the first step as the one chosen at least twice in three trials of gait initiation.

Gait initiation was performed after the assessment of quiet standing posture which was the first part of our study published elsewhere[12]. During tests on land and in water, following 5-10s of standing, participants were instructed to initiate gait with their preferred leg at a self-selected speed as soon as the visual cue (a light positioned about 3.5m anterior to the participants’ eye level) turned on. They continued walking up to 4 steps until the end of the pathway. In water, participants walked at approximately 1m deep and were asked to maintain upper limbs just above the water without touching the water surface. The same arm posture that was used during walking in water was adopted during dry land trials. Participants were allowed to practice gait initiation twice before the actual experiments, to help participants select their comfortable walking speed and to learn how to maintain consistent posture of the arms.

Data from 10 trials were acquired both in water and on dry land. The experiments in water and on dry land were conducted on two consecutive days, and the order of the experiments was randomized among the participants.

Data analysis

Data analysis was performed using *Matlab* (R2015b, Mathworks, USA). First, all signals were filtered using a second-order Butterworth filter with a cut-off frequency of 10Hz for the COP and forces, and a cut-off frequency of 30Hz for the acceleration.

The COP mean position during 2-s quiet standing was calculated in relation to the ankle line and to the lateral borders of the feet. We calculated a ratio of the distance between the mean COP position to the left foot border over the distance of the mean COP position to the right foot border (COP-ML symmetry). The borders of the feet were taken from the feet contour drawn on the force plate.

Figure 1 illustrates the time series of the COP trajectories, normalized GRF components, upper and lower trunk acceleration and the free vertical moment (FVM), with events of gait initiation (1, 2, and 3) of a representative single trial from a single subject. The events of gait initiation cycle were the following:

1. Onset of APA phase, defined on the COP trajectory in ML direction as the time when the COP increased more than 2 standard deviations of its mean value during 2-s of quiet standing[13][14].

2. End of APA phase, which corresponds to the point where the peak of COP in ML direction returns to the baseline[13]. This point approximates to the heel-off event and was used to set the beginning of step execution in all signals.

3. End of Execution phase determined as the heel-strike of the swing limb, which was identified as the negative peak of FVM[15].

Figure 2 exemplifies a COP trajectory in 2D-plane of a representative single trial from a single subject. In addition to the events of gait initiation, we defined an event on this plane; the time of the turning point on the COP trajectory from ML to AP direction (■), which approximates to the toe-off of swing limb[16] (Figure 2). The APA phase was defined from the event 1 to the event 2, the EXE1 was defined from event 2 to the approximate toe-off of swing limb (**■)**, and the EXE2 was defined from toe-off (■) to the event 3 (Figure 2).

Dependent variables

The percentage of body weight (BW) offloading when participants were immersed in water was calculated as $\%offloading=((BW_{land}–BW_{water})/BW_{land})*100$. BW on dry land and in water were measured by the vertical force on the force plate calculated during the last 2-s of quiet standing prior to walking.

During APA and EXE phases, the duration, length and velocity in AP and ML directions of COP trajectories were calculated. Additionally only for ML direction during APA, the peak of COP trajectory was defined using the COP trajectory in ML direction as the point where COP moved most lateral toward the first swing limb[2][17] (* in Figure 2). As the similar event in AP direction was not a repeatable event across participants, especially in water, we did not identify it. During each of EXE1 and EXE2, length and velocity of the COP trajectory were calculated.

The impulses for GRF vertical and AP components were calculated as the area under the force versus time curve during EXE. Non-normalized and body-weight-normalized GRF components were calculated. The normalized average force amplitudes were also calculated for vertical and AP GRF components during EXE. The normalized peak of force was calculated in AP direction.

From the acceleration signals, the root mean square (RMS) acceleration of upper and lower trunk in AP and ML directions were calculated during EXE. Further, acceleration ratio of upper to lower trunk was calculated in both of AP and ML directions, in order to analyze the trunk strategy in maintaining postural balance during gait initiation.

Statistical analysis

All analyses were conducted using a statistical package (SPSS Statistics 21, IBM, USA). The ten trials of gait initiation were averaged for each participant, and paired t-tests were performed to compare the group mean in water and on dry land for each dependent variable. Pearson correlation coefficient was used to report the relationship between parameters. Alpha level of 0.05 was set for all statistical tests. Effect sizes were expressed in Cohen’s *d* for matched samples.

Results

The percentage of BW offloading in water varied from 38.6% to 62.8% and was negatively correlated with individuals’ height (r=-0.712, *P=0.021*) and positively correlated with the normalized AP impulse (r=0.901, *P<0.001*) and normalized AP mean force (r=0.685, *P=0.029*) in water. There was no difference on the COP mean position in relation to the ankle line (*d*=0.08, *P*=0.799) and to the lateral borders of the feet (*d*=0.01, *P*=0.974) (Table 1).

Table 1 depicts parameters of COP trajectories during APA, EXE1 and EXE2. Significant differences were found for APA and EXE2 between in water and on land trials. During APA, COP duration (*d*=1.31, *P*=0.003), length in AP (*d*=1.16, *P*=0.005) and ML (*d*=3.36, *P*<0.0001) directions were larger in water than on land; Peak ML was increased in water (*d*=3.22, *P*=<0.0001); and COP velocity was also increased in water in AP (*d*=0.72, *P*=0.048) and in ML direction (*d*=1.20, *P*=0.004). In EXE1, there was no significant difference in any comparisons. In EXE2, COP duration (*d*=3.93, *P*<0.0001) and length increased in AP (*d*=2.35, *P*<0.0001) and ML (*d*=2.13, *P*<0.0001), while COP velocity decreased in AP (*d*=2.36, *P*<0.0001) and ML (*d*=1.09, *P*=0.007) directions in water compared to land.

Table 2 displays the impulses during EXE phases. The impulse duration was longer in water than on land (*d*=3.79, *P*<0.0001). The non-normalized impulse in AP direction was larger in water than on land (*d*=1.64, *P*=0.001) while the non-normalized vertical impulse decreased in water (*d*=2.88, *P*<0.0001). The normalized vertical (*d*=3.94, *P*<0.0001) and AP (*d*=4.28, *P*<0.0001) impulses were larger in water compared to land. The normalized AP impulse was 3 times larger in water than on land. The normalized mean AP-GRF component was larger by about 53% (*d*=3.71, *P*<0.0001) in water compared to land and the normalized mean vertical GRF component was slightly smaller (2.5%) in water (*d*=3.02, *P*<0.0001). The normalized peak of AP force increased in water compared to land (*d*=0.88, *P*=0.021).

Table 3 displays trunk acceleration results. Lower trunk acceleration was smaller in water compared to land in both of AP (*d*=1.87, *P*<0.0001) and ML (*d*=1.27, *P*=0.003). Upper trunk acceleration did not differ between the conditions in AP (*d*=0.13, *P*=0.689) and ML (*d*=0.45, *P*=0.189). The acceleration ratio increased about three times during execution phase in water compared to on land in AP direction (*d*=1.17, *P*=0.005), while no difference in ML (*d*=0.34, *P*=0.318).

Discussion

The present study proposed a new, detailed design of the COP trajectories defining APA based on the COP displacement in ML direction. In a previous study, the COP in ML direction has shown to be more consistent and reliable to detect APA than the acceleration signals[14].Therefore the COP in ML direction was used to divide the gait initiation cycle in APA and EXE phases across all signals analyzed in the study. Further, we subdivided EXE phase in EXE 1 and EXE2 as we expected that the aquatic medium would influence weight transfer to stance limb (EXE1) and stepping forward (EXE2) differently in AP and ML directions.

Our findings showed that COP trajectories were significantly longer in water compared to on land condition during APA and EXE2 (stepping forward), with substantial decrease in velocity while individuals stepped forward, which agrees with our findings in the pilot study[11]. Additionally, we found that the non-normalized and normalized AP impulses and the normalized mean AP force were larger in water compared to on land. Further, we found that the ratio upper to lower trunk acceleration was larger in water in AP direction, as a result of substantially smaller lower trunk acceleration in water compared to on land.

Although the biomechanical analysis of steady-state locomotion in water investigated important underlying mechanisms of the aquatic medium on muscle activity[18], joint forces and torques[19], and joint kinematics[20][21]; to date, only our preliminary study highlighted the effects of immersion in water on gait initiation performance by means of biomechanical parameters[11]. Agreeing with our preliminary study, our current findings solidify the evidence that gait initiation in water is longer and slower than gait initiation on land with larger COP length and substantial decrease in COP velocity when individuals were moving forward, especially in AP direction. During APA, the length and velocity were larger more significantly in ML direction than in AP direction in water compared to on land. In water, the individuals seemed to more rapidly adjust for the execution of the first step during APA, whereas during stepping forward, the COP trajectory slowed down while individuals faced a greater amount of water resistance. However, a larger length in water was observed during stepping forward both in AP and ML direction, indicating that the buoyant force was also playing a role in supporting the body to execute a longer COP trajectory before the heel-strike of the first swing limb. The EXE1 did not change between environments. In our pilot study, the entire section from APA ML peak to approximate swing limb toe-off increased in water compared to land[11]. This result interpreted in the light of the present study indicates that a greater change in COP ML trajectory during transfer to the stance limb occurred during APA and not during EXE1.

In the present study, we analyzed the impulses in AP and vertical directions during EXE in non-normalized and body-weight-normalized conditions. In non-normalized conditions, vertical impulse substantially decreased and AP impulse increased in water compared to land. In normalized conditions, both vertical and AP impulses were larger in water in comparison to on land trials. Knowing that the duration of impulses was longer in water than on land, we further compared the normalized average force components of vertical and AP impulses. In water, the average vertical force was minimally smaller and the AP average force was larger compared to on land. The increased AP impulse in non-normalized and normalized conditions suggests an evidence for water resistance against the lower body while stepping forward and the decrease in the non-normalized vertical impulse reveals the effect of buoyancy. Furthermore, our findings revealed that as the BW offloading increased the impulse and mean AP force increased in water. This result may indicate water drag force imposed more resistance in subjects with larger BW offloading.

A recent study found that the anterior impulse under the stance limb was smaller in the paretic and non-paretic limb of patients with stroke in comparison to able-bodied individuals[22]. Therefore, individuals with smaller AP impulse during gait initiation, such as those with stroke, could potentially benefit from an initial training in the aquatic environment that requires from them to apply higher levels of forces in AP direction. A gradual weight-bearing under the effect of water resistance could potentially prepare this individual to execute higher impulses on land.

Our new approach to analyze the upper and lower trunk acceleration allowed us to observe that the overall trunk acceleration was smaller during gait initiation in water in comparison to on land condition. In water, the lower trunk acceleration was much smaller compared to on land, while the upper trunk acceleration did not differ between the environments, resulting that the upper/lower trunk AP acceleration ratio was threefold larger in water compared to on land condition. This result revealed a clear influence of water resistance on the lower trunk leading to a reverse upper trunk-lower trunk acceleration pattern required to execute the first steps of gait in water. A previous study has used the upper trunk and lower trunk accelerations to measure attenuation of upper trunk acceleration as an output of improved balance control during gait in patients with vestibular disorders[23]. The attenuation of upper body acceleration in relation to the lower body was reported as an evidence for postural dynamic stability during gait in able-bodied subjects[24]. In fact, in our study, when individuals walked on land, the upper trunk acceleration was substantially attenuated in comparison to the lower trunk in both AP and ML directions during execution of the first step. In water, there was an attenuation of acceleration in the lower trunk in ML direction while the upper trunk acceleration in AP direction was maintained. Therefore, the aquatic environment required a different control strategy from the trunk to keep balance while initiating gait in water.

All the challenges imposed by the aquatic environment on the postural adjustment and execution of the first step, as shown by COP, impulses and trunk acceleration parameters may be applied as stimuli for balance and strength gains in populations with neurological disorders and other types of impairments.

Limitations

We used the end of APA on the COP trajectory in ML direction as a marker between APA and EXE phases, for lacking a sensitive kinematic parameter (i.e. heel-off) to determine the beginning of EXE phase of gait initiation. We recognize that this parameter may not be the most precise measure to indicate the heel-off event, especially in water.

Conclusions

Aquatic environment leads to an increased length of COP trajectories and slower COP execution during the first step compared to on land condition. The larger AP mean force aligned with a change in the trunk acceleration pattern seemed to be a compensatory strategy to overcome the drag force during gait initiation in water. Walking in water offers considerable BW offloading and movement resistance, which challenges postural control during anticipatory and execution phases of gait initiation.

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Table 1. Duration, length and velocity of center of pressure (COP) trajectories in water and on land. The results are presented separately in intervals of gait initiation (Anticipatory Postural Adjustment Phase - APA, Execution Phase 1 – EXE1 and Execution Phase 2 – EXE2) as mean ±1SD (N=10).

COP Trajectories	**Environment**		**Mean Diff**		***d***	***P* value**
	Land	**Water**	**Absolute**	**%**		
COP distance to ankle line (cm)	2.99 ± 2.01	2.82 ± 1.13	0.17	5.65	0.08	0.799
COP ML symmetry ratio	1.28 ± 0.78	1.29 ± 0.62	0.01	0.78	0.01	0.974
APA						
Duration (s)	0.435 ± 0.081	0.524 ± 0.086	0.089	20.33	1.31	***0.003***
Length AP (cm)	4.51 ± 1.86	6.41 ± 1.85	1.90	42.16	1.16	***0.005***
Length ML (cm)	6.98 ± 2.88	9.67 ± 3.27	2.69	38.57	3.36	***<0.0001***
Peak ML (cm)	3.42 ± 1.44	4.74 ± 1.66	1.32	38.64	3.22	***<0.0001***
Velocity AP (cm/s)	10.88 ± 5.19	13.15 ± 5.40	2.27	20.85	0.72	***0.048***
Velocity ML (cm/s)	16.59 ± 6.95	19.92 ± 8.73	3.33	20.06	1.21	***0.004***
EXE1						
Duration (s)	0.193 ± 0.048	0.213 ± 0.046	0.021	10.75	0.37	0.250
Length AP (cm)	2.76 ± 0.75	2.80 ± 1.44	0.04	1.28	0.02	0.952
Length ML (cm)	8.92 ± 2.23	8.75 ± 1.81	0.16	1.83	0.15	0.649
Velocity AP (cm/s)	14.67 ± 4.07	14.12 ± 9.05	0.55	3.77	0.07	0.830
Velocity ML (cm/s)	50.64 ± 20.93	45.29 ± 15.93	5.35	10.56	0.58	0.099
EXE2						
Duration (s)	0.464 ± 0.065	0.859 ± 0.081	0.395	85.11	3.93	***<0.0001***
Length AP (cm)	11.46 ± 1.53	13.72 ± 1.27	2.26	19.73	2.35	***<0.0001***
Length ML (cm)	2.07 ± 0.76	2.85 ± 0.64	0.78	37.59	2.13	***<0.0001***
Velocity AP (cm/s)	25.22 ± 4.89	16.34 ± 2.89	8.89	35.23	2.36	***<0.0001***
Velocity ML (cm/s)	4.50 ± 1.66	3.37 ± 0.93	1.14	25.24	1.09	***0.007***

Note. Mean diff: mean of the difference between land and water values, expressed in absolute value and percentage of change in water based on the land values. *d*: Cohen’s d effect size for matched pairs. APA: anticipatory postural adjustment phase. AP: anteroposterior. ML: mediolateral.

Table 2. Impulses and mean ground reaction force components exerted during execution of gait initiation. Values are expressed in mean±1SD (N=10).

Variables	**Environment**		**Mean Diff**		***d***	***P* value**
	Land	**Water**	**Absolute**	**%**		
Duration of Impulses (s)	0.655 ± 0.089	1.070 ± 0.11	0.416	63.47	3.79	***<0.0001***
			Non-Normalized Impulse			
Vertical GRF Impulse (N.s)	426.97 ± 87.05	319.95 ± 76.37	107.02	25.07	2.88	***<0.0001***
AP GRF Impulse (N.s)	40.07 ± 10.02	46.72 ± 8.17	6.65	16.6	1.64	***0.001***
			Normalized Impulse Calculations			
Vertical GRF Impulse (%BW.s)	65.27 ± 8.70	103.99 ± 10.09	38.73	59.33	3.94	***<0.0001***
AP GRF Impulse (%BW.s)	6.10 ± 1.04	15.55 ± 3.00	9.45	154.86	4.28	***<0.0001***
AP Impulse Peak (%BW)	17.81 ± 3.69	20.41 ± 4.66	2.60	14.59	0.88	***0.021***
Mean Vertical Impulse (%BW)	99.74 ± 0.86	97.24 ± 1.15	2.51	2.51	3.02	***<0.0001***
Mean AP Impulse (%BW)	9.63 ± 2.67	14.77 ± 3.51	5.13	53.29	3.71	***<0.0001***

Note. Mean diff: mean of the difference between land and water values, expressed in absolute value and percentage of change in water based on the land values. GRF: ground reaction force. BW: body weight. *d*: Cohen's d effect size for matched pairs. AP: anteroposterior.

Table 3. Trunk root mean square accelerations and upper to lower trunk ratios during execution phase. Values are expressed in mean±1SD (N=10).

Trunk Acceleration	**Environment**		**Mean Diff**		***d***	***P* value**
	Land	**Water**	**Absolute**	**%**		
Upper Trunk						
RMS AP (m/s^2)	0.502 ± 0.236	0.537 ± 0.299	0.035	6.98	0.13	0.689
RMS ML (m/s^2)	0.466 ± 0.247	0.376 ± 0.155	0.090	19.31	0.45	0.189
Lower Trunk						
RMS AP (m/s^2)	1.479 ± 0.605	0.519 ± 0.206	0.960	64.92	1.87	***<0.0001***
RMS ML (m/s^2)	1.018 ± 0.301	0.764 ± 0.281	0.254	24.91	1.27	***0.003***
Upper/Lower Trunk Ratio						
RMS AP	0.369 ± 0.137	1.233 ± 0.728	0.864	234.46	1.17	***0.005***
RMS ML	0.467 ± 0.186	0.538 ± 0.264	0.071	15.10	0.34	0.318

Note. Mean diff: mean of the difference between land and water values, expressed in absolute value and percentage of change in water based on the land values. RMS: root mean square. *d*: Cohen’s d effect size for matched pairs. AP: anteroposterior. ML: mediolateral.

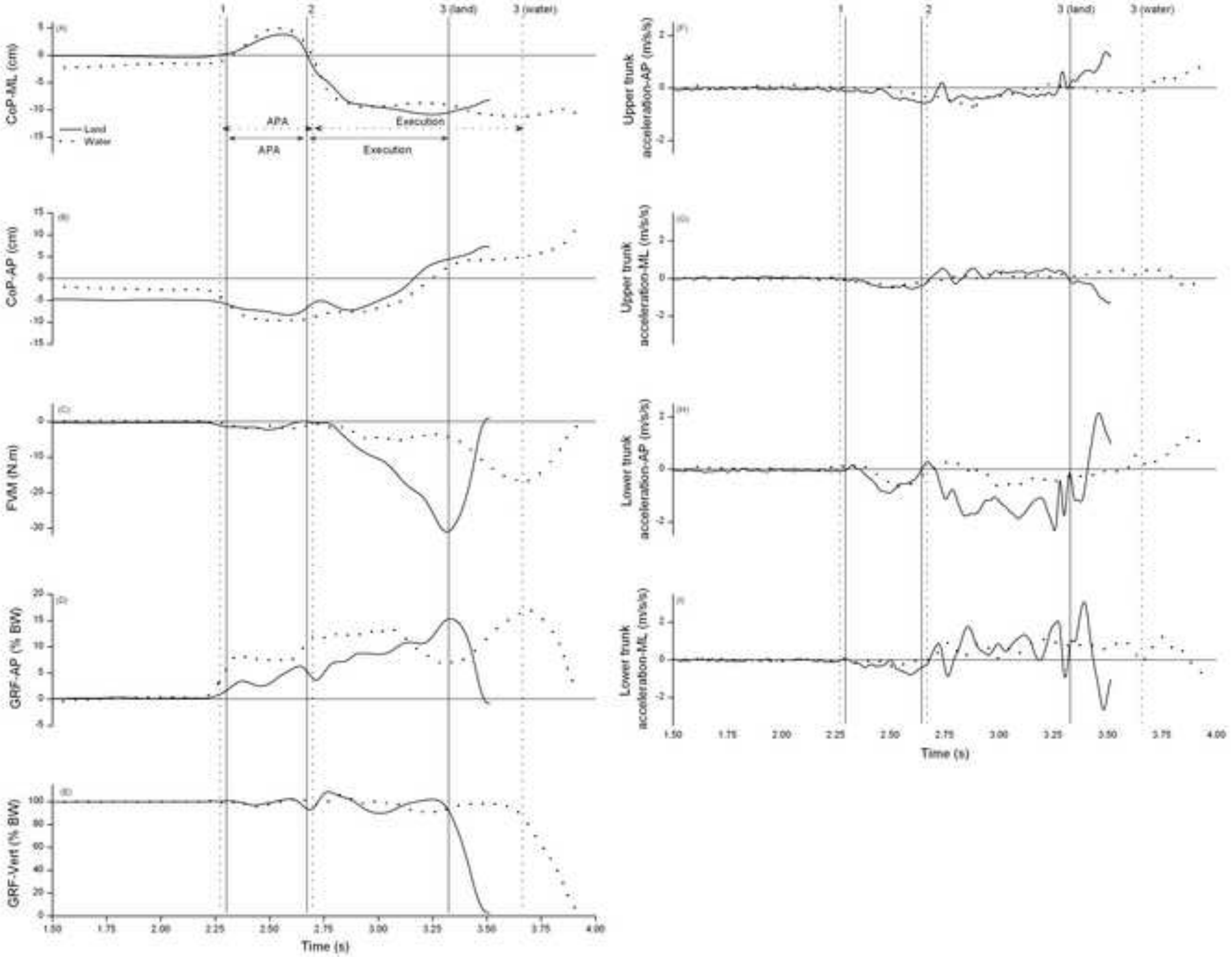
FIGURE CAPTIONS

Figure 1. This figure presents events of gait initiation of a representative single trial from a single subject. Dashed line: Data measured in water. Continuous line: Data measured on land. On the left side: A) Center of pressure (COP) in mediolateral direction (COP-ML), B) COP in anteroposterior direction (COP-AP), C) Free vertical moment (FVM), D) Anteroposterior ground reaction force (GRF-AP), and E) Vertical ground reaction force (GRF-Vert). On the right side: F) Upper trunk acceleration in anteroposterior direction, G) Upper trunk acceleration in mediolateral direction, H) Lower trunk acceleration in anteroposterior direction, and I) Lower trunk acceleration in mediolateral direction. The events dividing the gait initiation cycle are: 1) Onset of anticipatory postural adjustment phase (detected on the COP-ML), 2) End of anticipatory postural adjustment phase (detected on the COP-ML), 3) End of gait initiation cycle detected on the negative peak of the free vertical moment (FVM), which corresponds to the heel-strike of the first swing limb. *Note:* the figure starts at second 1.5 in order to give emphasis to the gait initiation cycle. In the analysis, a quiet standing period of 2 seconds was considered.

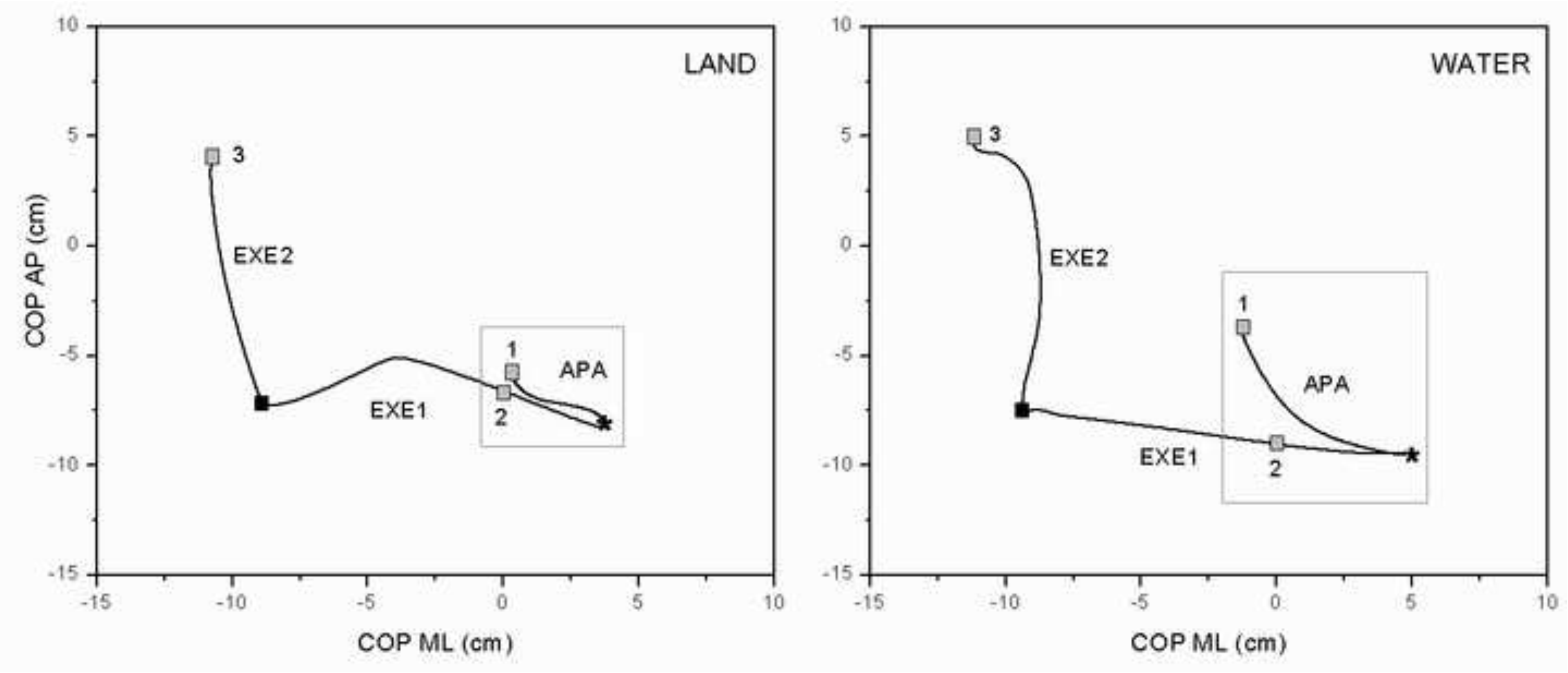
Figure 2. Center of pressure (COP) horizontal trajectories during gait initiation of a representative single trial from a single subject on land (left) and in water (right). 1) Onset of anticipatory postural adjustment phase (detected on the COP-ML), 2) End of anticipatory postural adjustment phase (detected on the COP-ML), 3) End of gait initiation cycle detected on the negative peak of the free vertical moment (FVM). (*****) indicates the mediolateral peak of anticipatory postural adjustment (APA peak), and (■)

indicates the most lateral and posterior landmark towards the first stance limb. APA phase was defined from the event 1 to the event 2. EXE1 was defined from the event 2 to (■)**,** and EXE2 was defined from (■) to the event 3.

7. Figure1_R2


1
2
3 (land)
3 (water)
(A)
CoP-ML (cm)
5
0
-5
-10
-15
Land
Water
APA
Execution
APA
Execution
(B)
CoP-AP (cm)
15
10
5
0
-5
-10
-15
(C)
FVM (N.m)
0
-10
-20
-30
(D)
GRF-AP (% BW)
20
15
10
5
0
-5
(E)
GRF-Vert (% BW)
100
80
60
40
20
0
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
Time (s)
(F)
Upper trunk acceleration-AP (m/s/s)
2
0
-2
(G)
Upper trunk acceleration-ML (m/s/s)
2
0
-2
(H)
Lower trunk acceleration-AP (m/s/s)
2
0
-2
(I)
Lower trunk acceleration-ML (m/s/s)
2
0
-2
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
Time (s)

7. Figure 2


LAND
WATER
COP AP (cm)
COP ML (cm)
COP ML (cm)
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
1
2
3
APA
EXE1
EXE2