Title

Quantifying the acute responses of shallow-water immersion on walking physiology and biomechanics: a systematic review and meta-analysis

Running title

Shallow water walking parameters: systematic review

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Abstract

Shallow water walking (SWW) generates changes in cardiorespiratory parameters in comparison to terrestrial exercise, and these changes are highly dependent of immersion depth. We reviewed the evidence from observational studies focusing on physiological and biomechanical responses of SWW in comparison to dry land walking. This systematic review and meta-analysis (initial search: 1516 studies; systematic review: 40 studies; meta-analysis: 22 studies) presents evidence that higher energy expenditure, heart rate and rating of perceived exertion are accompanied by depth-dependent reductions in self-selected speed and stride length in SWW compared with dry land. The stride frequency, however, was similar at waist and reduced at xiphoid depth. As expected, the ground reaction forces were reduced according to the buoyance forces acting. SWW appears to increase muscular activity. Importantly, the depth-related increase in energy expenditure of SWW seems to involve a major role of resistive forces compensating the reduced task of support the body weight. Besides the benefits of water immersion as reduced joint impact and safety, biomechanical alterations on force production may produce additional long-term gains in functional mobility. However, the influence of these physiological and biomechanical alterations on functional mobility are largely unknown. Due to these inconclusive points, there is a huge opportunity to determine (1) the alterations on muscle activation in different depths in order to explain the higher energy expenditure at organismal level, and (2) whether these alterations can maximize gains in metabolic economy and gait biomechanics after long-term SWW intervention. PROSPERO registration protocol: CRD42018113040.

Keywords: head-out aquatic immersion; locomotion; metabolic cost; aquatic exercise; biomechanics

1. Introduction

Exercise in aquatic environment is a feasible and recommended intervention to a wide range of populations. The practice of physical exercise in water is advantageous to a variety of health conditions, having benefits in pain (5, 22, 60, 63), muscle strength

(7, 8, 72, 74), mobility (22), equilibrium (75), flexibility (7, 72), cardiorespiratory capacity (72), functionality (7, 63, 74, 75). The benefits from the aquatic exercise intervention can be associated with the physical characteristics of this environment. In this way, the shallow water walking (SWW) is a popular method of water immersion exercise (43, 68).

The locomotion is dependent from environment and task constraints (12, 19, 59). While, in water immersion, the relative high density induces the addition of two forces neglected in dry land walking (DLW): drag and buoyancy forces (19). The drag force (DrF) is a force that resists to the displacement of a body immersed in a fluid. The drag force magnitude is directly dependent to the density of the fluid, the cross-sectional area of the moving body, a fluid drag coefficient, and the square of the relative velocity of the body in relation to the fluid (19). Therefore, the higher water density generates a higher DrF at a given walking velocity in aquatic environment in comparison with land. The buoyancy force (B) is the vertical force in opposite direction to the gravitational force, resulting from the difference in the gradient of hydrostatic pressure applied to the immersed body, and is directly dependent of the displaced fluid mass (55). Accordingly, greater the immersion depth, greater body volume immersed, greater the B, and smaller the apparent body weight to be supported and propelled by the locomotor system.

In comparison to DLW, SSW presents altered physiological and biomechanical parameters such as increased energy expenditure and heart rate (HR) (27), and reduced range of motion (ROM) and kinetic parameters (4). Heywood et al. (33) developed a systematic review comparing gait parameters in water and dry land. Their search comprised spatiotemporal, kinematic, kinetic, and muscular activity parameters. Despite the many variables analyzed, a meta-analytic approach to examine changes in metabolic economy of SWW is lacking (19). Also, the role from depth immersion on physiological and biomechanical parameters is unknown. Furthermore, the findings on energy expenditure parameters are controversial in previous studies. Some studies have found that water immersion produces higher (2, 6, 30) values and others have found similar (2, 30, 70) values of energy expenditure in shallow water in comparison to dry land.

Therefore, this review 1) systematically appraised the available evidence from observational studies, analyzing the physiological and biomechanical responses of

SSW in comparison to DLW and testing the influence of immersion depth in healthy adults and elderly; 2) meta-analytically pooled physiological and biomechanical measurements comparing the SSW and DLW responses; and 3) provides scoping lines for future research to enhance the understanding of potential gain from SSW in the health context.

2. Methods

This systematic review was registered as protocol at PROSPERO (registry number CRD42018113040) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was followed in order to conduct and to report this study.

Data extraction and quality assessment

The search strategy was elaborated accordingly to the PICOT strategy. Combinations from the subsequent terms were used: “walk”, “gait”, “shallow water”. The search was conducted at November of 2018 and actualized at September of 2019 in PubMed Medline, Cochrane, Scopus, and Embase databases, including studies from inception until the search date. Handsearching was also performed by the reference lists of obtained articles at the digital databases.

Eligibility criteria

The studies included in this systematic review were selected based on the subsequent inclusion criteria: i) Participants: healthy adults and/or elderly; ii) Experimental condition: walking in shallow water at any depth. Studies that evaluated walk in dry land were also included only if they have evaluated walk in shallow water as well; iii) Outcomes variables analyzed: spatiotemporal, articular range of motion, ground reaction forces, muscle activity, physiologic parameters; iv) Study design: observational or experimental; v) Publication in peer-reviewed journal in english or portuguese language.

Selection of studies

After the search in databases, two reviewers (A.I.M and M.Z.C) selected independently the studies in the following steps: 1) Screening: the studies found in the databases were first selected accordingly the inclusion criteria by title and abstract, also the duplicates were excluded. 2) Eligibility: the studies remaining from step 1 were evaluated accordingly the inclusion criteria by their full text reading. 3) Inclusion in the systematic review: the studies remaining from step 3 were considered included in the systematic review. 4) Inclusion in the meta-analysis: the meta-analysis was performed for a specific variable when a sufficient number of studies using the same unit of measure compared the variable in different depths in similar experimental conditions (speed of walking, for example). In case of disagreement between different views a third author was consulted.

Data extraction and quality assessment

The extraction of data from the studies included in the systematic review was made independently by two reviewers (A.I.M and M.Z.C). The data extracted of each included study was the following: authors, year of publication, number of participants, age from the participants, depth of immersion, water temperature, local of walking (floor or treadmill), speed control method, speed of walking, and physiological, spatiotemporal, angular, kinetic, and neuromuscular parameters. In case of missing data, a written solicitation was sent by e-mail to the authors of the article.

The data extracted for each parameter were: 1) Physiological: energy expenditure, HR, rating of perceived exertion (RPE). 2) Spatiotemporal: speed, stride frequency, stride length, stride duration, duty factor. 3) Angular: articular ROM. 4) Kinetic: ground reaction forces, joint moments. 5) Neuromuscular: electromyographic activity (EMG).

The quality assessment of the included studies was performed with a checklist based on Downs and Black (21). There was a total of 8 questions to be checked. Each question was rated as 2 (satisfying description), 1 (limited details), or 0 (no information). The methodological quality of the studies was rated according to criteria proposed by Hootman et al. (35) in percentage of the total possible score achieved by the study as: low ($\leq 33\%$), moderate (33.4% to 66.7%), and high ($\geq 66.8\%$).

Data analysis

A meta-analysis was conducted. The comparisons were performed between land and one specific immersion depth. The depths selected were those with sufficient available data to perform meta-analysis. The mean and standard deviation values of physiological, spatiotemporal, angular, and kinetic parameters were used. Results are presented as standardized mean differences. Both fixed and random effect models were used. The inconsistency was evaluated using the I^2 test, and heterogeneity level was evaluated accordingly to Higgins et al. (34). Forest plots were generated to present the pooled effect and the standardized mean differences (SMD) with 95% confidence intervals (CI). The statistical significance level was $\alpha = 0.05$. The analyzes were conducted using in RStudio (1.3.1056, PBC, Boston, USA).

3. Results

Studies selection

The initial search at databases resulted in 1516 studies, of which 196 duplicates were excluded (Figure 1). After title and abstract screening, 64 studies remained for the full text reading assessment. Of these, 34 studies were included; and 6 more additional studies from the reference lists of the included studies were selected. Therefore, a total of 40 (2–4, 6, 10, 11, 15–17, 20, 23, 24, 26–28, 30, 31, 36–40, 42, 44, 46–49, 51–54, 56, 61, 62, 65–67, 70, 73) studies were included in this systematic review.

Figure 1 - Flow chart of studies research and selection for inclusion.

Characteristics of included studies

All data are available at supplementary material (DOI: 10.6084/m9.figshare.13225304). The studies characteristics are summarized in Table 1. Thirty-one studies have analyzed adults (2, 4, 6, 10, 11, 15, 16, 23, 24, 27, 30, 36–40, 42, 44, 46–49, 51–54, 56, 61, 62, 65, 73) (26.3 ± 4.5 years), and 10 (3, 17, 20, 26, 28, 36, 48, 66, 67, 70) studies analyzed elderly (63.9 ± 3.8 years). The total number of subjects was of 572, with a mean of 14 ± 7 subjects per study (minimum of 6 and a maximum of 60 subjects per study).

From the 40 studies included, 21 (3, 4, 10, 11, 15, 17, 23, 24, 31, 36, 38, 40, 42, 51–54, 56, 62, 70, 73) performed the walking at the pool floor, while 20 (2, 16, 20, 23, 26–28, 30, 37, 39, 44, 46–49, 61, 65–67, 73) performed the walking at motorized treadmill, and one (6) at non-motorized treadmill. Eighteen studies controlled the walking speed (3, 4, 11, 15, 17, 24, 26, 31, 36, 38, 40, 47, 51–53, 56, 62, 70) by self-selected determination of speed, 17 studies (2, 16, 20, 23, 27, 30, 37, 39, 44, 46, 48, 49, 61, 65–67, 73) used treadmill control, six studies (6, 10, 16, 23, 47, 54) used metronome frequency determination, one study (28) used HR levels to determine the walking speed, and two studies (42, 73) controlled the speed of walking by synchronizing the volunteer location against markers in the space.

The upper limb orientation during the walking in water was predominantly free (28 studies; (2, 6, 15–17, 20, 23, 24, 26–28, 31, 38–40, 42, 46–49, 51–54, 62, 65, 70, 73) , while five studies (30, 44, 61, 66, 67) allowed upper limb swing, five studies (3, 4, 36, 37, 56) oriented to maintain the upper limbs outside of water, and two studies (10, 11) oriented to cross arms at the chest.

About water temperature, nine studies (3, 4, 10, 17, 31, 36, 42, 54, 62) did not report water temperature, two reported the range 30 to 31° C (23, 44) and one study reported 25.0 to 27.2 °C (73). For the other 28 studies (2, 6, 11, 15, 16, 20, 24, 26–28, 30, 37–40, 46–49, 51–53, 56, 61, 65–67, 70) the mean temperature was $30.5 \pm 2.2^\circ$ C, with a minimum of 16.7° C (40) and a maximum of 35.8° C (30).

About the depths studied, 38 studies (2–4, 10, 11, 15–17, 20, 23, 24, 26–28, 30, 31, 36, 38–40, 42, 44, 46–49, 51–54, 56, 61, 62, 65–67, 70, 73) used land as a comparator of SWW. The water depth was determined by anatomical landmarks: ankle (27); knee (27); thigh (27, 61); iliac crest (6, 20, 28); waist (23, 37, 39, 73); umbilicus

216 (16, 27, 61); xiphoid (2–4, 6, 10, 11, 15, 17, 26, 30, 44, 46–49, 56, 62, 65–67); 0.1 m
217 below xiphoid (2); 0.1 m above xiphoid (2); 0.05 to 0.10 m above xiphoid (15); axillar
218 (51–53, 70); neck (37). In terms of absolute depth, the values were: 0.4 m depth (54);
219 0.5 m depth (40); 0.7 m depth (54); 0.96 m depth (42); 1.0 m depth (54); 1.1 m depth
220 (31, 38); 1.2 m depth (24, 36, 42, 54); 1.3 m depth (31).

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223 **Table 1** - Characteristics of the included studies

Study	N (male)	Age	Depths	Floor or treadmill	Speed control	Variables							
						ST	AA	EMG	VO2	HR	GRF	JM	RPE
Alkurdi et al. 2010	18 (0)	45 ± 1.3							X	X			X
Barela & Duarte, 2008	10 (6)	70 ± 4.5				X	X	X				X	
Barela et al., 2006	10 (4)	29 ± 6				X	X	X				X	
Benelli et al., 2014	15 (0)	43 ± 3.7		(Non-motorized)		X			X	X			X
Cadenas-Sanchez et al., 2015	8 (4)	22 ± 1.1				X							
Carneiro et al., 2012	22 (11)	24.6 ± 2.6				X	X						
Chevustchi et al., 2009	31 (16)	22.8 ± 1.8				X							
Conti et al., 2015	8 (NI)	26.5 ± 2.8			Land: Water:				X	X			
Degani & Danna-dos-Santos, 2007	8 (NI)	62.5					X						
Dolbow et al., 2008	20 (13)	58.0 ± 2.1							X	X			X

Evans et al., 1978	6 (6)	21 to 42			Land: Water:	Land: Water:			X	X	
Fantozzi et al., 2015	11 (6)	27.0 ± 3.4		1.2 m			X	X			
Fujishima & Shimizu, 2003	9 (9)	67.9 ± 1.7							X	X	
Gleim & Nicholas, 1989	11 (6)	27.5 ± 1.8							X	X	
Gobbo et al., 2014	18 (18)	64.2 ± 2.9							X	X	X
Hall et al., 1998	8 (0)	30.2					X		X	X	X
Harrison et al., 1992	9 (3)	NI		1.1 m 1.3 m							X
Jabbar et al., 2017	51 (51)	A: 24.6 ± 4.9 B: 58.5 ± 5.1		1.2 m			X	X			
Jung et al., 2018	15 (9)	37.1 ± 10.9					X	X			
Kaneda et al., 2007	9 (9)	24.9 ± 2.2		1.1 m					X		
Kato et al., 2001	6 (6)	19.8 ± 1.3					X	X		X	
Kotani et al., 2009	8 (8)	22.8 ± 1.0		0.5 m			X		X		

Kuliukas et al., 2009	30 (14)	39.1 ± 15.4		0.96 m	1.2 m														X		
Lim & Rhi, 2014	9 (9)	23.2 ± 1.2																X	X		X
Masumoto et al., 2004	6 (6)	23.3 ± 1.4											X					X			
Masumoto et al., 2008	9 (0)	61.8 ± 3.8							X				X					X	X		X
Masumoto et al., 2012	7 (7)	21.6 ± 1.1							X									X	X		X
Masumoto et al., 2013	11 (11)	23.8 ± 4.2							X									X	X		X
Miyoshi et al., 2003	8 (8)	23.0 ± 2.3											X								X
Miyoshi et al., 2004	15 (15)	22.8 ± 4.5							X	X		X								X	X
Miyoshi et al., 2005	16 (12)	22.3 ± 2.7							X				X								X
Nakazawa et al., 1994	6 (4)	25.5 ± 2.3			0.4 m	1.0 m							X			X				X	
					0.7 m	1.2 m
Orselli & Duarte, 2011	10 (4)	24 ± 3							X	X										X	X
Pohl & McNaughton, 2003	6 (NI)	23.2 ± 2.9							X									X	X		
Ribas et al., 2007	19 (19)	24.1 ± 3.3											X								

Shimizu et al., 1998	8 (8)	19 ± 1									X	X	
Shono et al., 2001	6 (0)	62.2 ± 4.2					X				X	X	
Shono et al., 2007	8 (0)	61.4 ± 3.9					X	X	X		X	X	
Takeshima et al., 1997	15 (8)	79.9 ± 4.2					X				X	X	X
Whitley & Schoene, 1987	12 (0)	24.5 ± 5.4			Land:	Land:						X	
					Water:	Water:

Depths		Walking surface	Speed control		
Anatomical reference		Floor	Heart Rate	Self-Selected	Timed Lap
Metric reference	0.7 m	Treadmill	Metronome	Treadmill

AA: articular angular; EMG: muscular activity; GRF: ground reaction forces; HR: heart rate; JM: joint moments; NI: not informed; RPE: rating of perceived exertion; ST: spatiotemporal; VO2: energy expenditure. The depth of immersion in anatomical reference are (from shallower to deeper): dry land, ankle, knee, thigh, waist, xiphoid, axillar, neck.

Methodological quality

The methodological quality results are in Table 2. One study (31) was classified with low quality, seven (23, 38, 40, 42, 49, 54, 66) with moderate quality, and all the others were classified as high quality.

261 **Table 2** - Methodological quality analysis.

Study	Q1	Q2	Q3	Q6	Q7	Q10	Q18	Q20	Score (Absolute/ Percentual)	Quality Rate
Alkurdi et al. 2010	2	2	2	2	2	1	2	2	(15 / 94%)	High
Barela & Duarte, 2008	2	2	2	2	2	2	2	2	(16 / 100%)	High
Barela et al., 2006	2	2	2	2	2	0	2	2	(14 / 88%)	High
Benelli et al., 2014	2	2	1	1	2	0	2	2	(12 / 75%)	High
Cadenas-Sanchez et al., 2015	2	2	2	2	2	2	2	2	(16 / 100%)	High
Carneiro et al., 2012	2	2	2	2	2	2	2	2	(16 / 100%)	High
Chevustchi et al., 2009	2	2	2	2	2	0	2	2	(14 / 88%)	High
Conti et al., 2015	2	2	1	2	2	0	2	2	(13 / 81%)	High

Kaneda et al., 2007	2	2	1	0	1	0	2	2	(10 / 63%)	Moderate
Kato et al., 2001	2	2	2	2	2	0	2	2	(14 / 88%)	High
Kotani et al., 2009	1	2	2	0	1	0	1	2	(9 / 56%)	Moderate
Kuliukas et al., 2009	2	0	0	0	1	2	2	2	(9 / 56%)	Moderate
Lim & Rhi, 2014	2	2	2	2	2	0	2	2	(14 / 88%)	High
Masumoto et al., 2004	2	2	2	0	0	0	2	2	(10 / 63%)	Moderate
Masumoto et al., 2008	2	2	2	2	2	0	2	2	(14 / 88%)	High
Masumoto et al., 2012	2	2	2	2	2	0	2	2	(14 / 88%)	High
Masumoto et al., 2013	2	2	2	2	2	1	2	2	(15 / 94%)	High
Miyoshi et al., 2003	2	2	2	0	1	0	2	2	(11 / 69%)	High
Miyoshi et al., 2004	2	2	2	0	2	0	2	2	(12 / 75%)	High
Miyoshi et al., 2005	2	2	2	1	2	0	2	2	(13 / 82%)	High
Nakazawa et al., 1994	2	2	0	0	0	0	2	2	(8 / 50%)	Moderate

Orsell & Duarte, 2011	2	2	2	2	2	2	2	2	(16 / 100%)	High
Pohl & McNaughton, 2003	2	2	2	2	2	2	2	2	(16 / 100%)	High
Ribas et al., 2007	2	2	2	2	2	0	2	2	(14 / 88%)	High
Shimizu et al., 1998	2	2	2	1	2	0	2	2	(13 / 81%)	High
Shono et al., 2001	1	1	1	1	2	0	2	2	(10 / 63%)	Moderate
Shono et al., 2007	2	2	1	2	2	2	2	2	(15 / 94%)	High
Takeshima et al., 1997	2	2	2	2	2	0	2	2	(14 / 88%)	High
Whitley & Schoene, 1987	2	2	0	2	2	0	2	2	(12 / 75%)	High

Energy expenditure

Twenty studies (2, 6, 16, 20, 23, 26–28, 30, 39, 42, 44, 46–48, 61, 65–67, 70) have analyzed energy expenditure during walking. Except for Benelli et al. (6) that have compared exclusively two water depths conditions, all studies have compared energy expenditure between shallow water and dry land walking. All 20 studies have analyzed the energy expenditure normalized in the time domain, i.e. metabolic power (PMet), while only one (42) also have analyzed energy expenditure normalized in the space domain, i.e. cost of transport (C).

To perform the meta-analysis of energy expenditure, some considerations must be pointed out. Firstly, the meta-analysis was realized for studies that compared the same depth conditions. Secondly, only studies that analyzed the same walking speed in both depth conditions were included in the meta-analysis. Lastly, due to the different units used by the studies to report energy expenditure, we performed data unit adjustments.

These data unit adjustments were made to facilitate the comparison between the studies and to express the energy expenditure in Joules (J), accordingly to the International Unit System. Also, we calculate the energy expenditure normalized in the space domain. The meta-analysis of energy expenditure therefore was performed for both the units of J/kg/min (PMet) and J/kg/m (C) (59). It is worth noting that the C is calculated from the gross oxygen consumption values given by the studies, considering that only one study (16) informed energy expenditure in net oxygen consumption, but this study was not included in the meta-analysis because evaluated an incremental submaximal test.

From the twenty studies that evaluated energy expenditure, seven were included in meta-analysis (2, 20, 27, 30, 39, 48, 61). Thirteen were not included in meta-analysis for different reasons: compared different walking speeds between depths (26, 28, 44, 46, 70), controlled the stride frequency not the walking speed (47), evaluated a submaximal incremental test (16), do not have provided enough data information (23, 64–66), and evaluated different depths than the other studies (6, 42).

The PMet (J/kg/min) was higher in SWW at xiphoid depth than in DLW at even walking speed (SDM = 0.80; 95% CI: 0.32 to 1.28; $p < 0.01$; I^2 : 74%; 304.1 ± 105.1 vs. 252.0 ± 60.9 J/kg/min) (Figure 2).

295 **Figure 2** - Meta-analysis of metabolic power (J/kg/min) at even walking speed (xiphoid depth
 296 vs. dry land). Standard mean differences between walking in the same speed (1.16 ± 0.37 m/s)
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300 The PMet (J/kg/min) was higher in SWW at waist depth than in DLW at even
 301 walking speed (SMD = 3.76; 95% CI: 2.38 to 5.14; $p < 0.01$; I^2 : 94%; 295.5 ± 87.1 vs.
 302 227.1 ± 30.5 J/kg/min) (Figure 3).

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Figure 3 - Meta-analysis of metabolic power (J/kg/min) at even walking speed (waist depth vs. dry land). Standard mean differences between walking in the same speed (1.19 ± 0.42 m/s).

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318 The C (J/kg/m) was higher in SWW at xiphoid depth than in DLW at even
 319 walking speed (SDM = 0.79; 95% CI: 0.31 to 1.27; $p < 0.01$; I^2 : 75; 4.32 ± 1.38 vs. 3.62
 320 ± 0.69 J/kg/m) (Figure 4).

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331 **Figure 4** - Meta-analysis of cost of transport (J/kg/m) at even walking speed (xiphoid depth vs.
 332 dry land). Standard mean differences between walking in the same speed (1.20 ± 0.35 m/s).

334 The C (J/kg/m) was higher in SWW at waist depth than in DLW at even walking
 335 speed (SMD = 3.75; 95% CI: 2.37 to 5.13; $p < 0.01$; I^2 : 94%; 4.85 ± 0.54 vs. $3.90 \pm$
 336 0.81 J/kg/m) (Figure 5).

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338 **Figure 5** - Meta-analysis of cost of transport (J/kg/m) at even walking speed (waist depth vs.
 339 dry land). Standard mean differences between walking in the same speed (1.19 ± 0.42 m/s).

Spatiotemporal parameters

From the 13 studies that reported speed as dependent variable (3, 4, 6, 10, 11, 15, 24, 36, 47, 51, 53, 56, 70), 11 analyzed comfortable speed of walking (3, 4, 11, 15, 24, 36, 47, 51, 53, 56, 70) and three studies analyzed fast speed condition (15, 53, 70). Taking together the studies that have compared different water depths with DLW, both comfortable (0.46 ± 0.06 vs. 1.25 ± 0.13 m/s) and fast (0.63 ± 0.23 vs. 1.74 ± 0.40 m/s) walking speeds were lower in SWW.

From the 13 studies that analyzed speed as dependent variable, nine were included in meta-analysis (3, 4, 10, 11, 47, 51, 53, 56, 70). Four studies were not included in meta-analysis for different reasons: controlled the intensity by stride frequency (6), evaluated different depths than the other studies (15, 24, 36)

According to the meta-analysis, the SSS (m/s) was lower in SWW than DLW both at xiphoid depth (SMD = -6.51; 95% CI: -7.69 to -5.32; $p < 0.01$; I^2 : 39%; 0.48 ± 0.08 vs. 1.21 ± 0.17 m/s) (Figure 6), and at axillar depth (SMD = -6.38; 95% CI: -8.66 to -4.10; $p < 0.01$; I^2 : 78%; 0.50 ± 0.09 vs. 1.11 ± 0.13 m/s) (Figure 7).

Figure 6 - Meta-analysis of comfortable self-selected speed of walking (m/s) (xiphoid depth vs. dry land). Standard mean differences between conditions.

Figure 7 - Meta-analysis of comfortable self-selected speed of walking (m/s) (axillar depth vs. dry land). Standard mean differences between conditions.

The fast speed (m/s) was lower in SWW at axillar depth than DLW (SMD = -6.25; 95% CI: -12.59 to 0.09; $p = 0.05$; I^2 : 95%; 0.69 ± 0.37 vs. 1.40 ± 0.03 m/s) (Figure 8).

Figure 8 - Meta-analysis of fast self-selected speed of walking (m/s) (axillar depth vs. dry land). Standard mean differences between conditions.

The stride length (m) was lower in SWW at xiphoid depth than DLW at self-selected speed (SMD = -1.38; 95% CI: -2.19 to -0.57; $p < 0.01$; I^2 : 56%; 1.09 ± 0.18 vs. 1.28 ± 0.09 m) (Figure 9).

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380 **Figure 9** - Meta-analysis of stride length (m) at self-selected speed (xiphoid depth vs. dry land).
 381 Standard mean differences between conditions.

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385 The stride duration (s) was higher in SWW at xiphoid depth than DLW in self-
 386 selected speed (SMD: 6.40; 95%CI: 4.29 to 8.50; $p < 0.01$; I^2 : 64%; 2.4 ± 0.4 vs. $1.0 \pm$
 387 0.1 s) (Figure 10).

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389 **Figure 10** - Meta-analysis of stride duration (s) at self-selected speed (xiphoid depth vs. dry
 390 land). Standard mean differences between conditions.

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393 The stride frequency (strides/min) was lower in SWW at xiphoid depth than DLW
 394 at even speed (SMD: -4.67; 95%CI: -6.99 to -2.35; $p < 0.01$; I^2 : 80%; 84.7 ± 9.6 vs. 114.7
 395 ± 8.6 strides/min) (Figure 11).

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397 **Figure 11** - Meta-analysis of stride frequency (strides/min) at even walking speed (xiphoid
 398 depth vs. dry land). Standard mean differences between walking in the same speed ($1.11 \pm$
 399 0.37 m/s).

401

402 The stride frequency was similar in SWW at waist depth than DLW at even
 403 walking speed (SMD: -0.56; 95%CI: -1.24 to 0.12; $p = 0.10$; I^2 : 0%; 63.7 ± 25.4 vs. 72.4
 404 ± 26.7 strides/min) (Figure 12).

405

406 **Figure 12** - Meta-analysis of stride frequency (strides/min) at even walking speed (waist depth
 407 vs. dry land). Standard mean differences between walking in the same speed (0.92 ± 0.31
 408 m/s).

The duty factor (%) was lower in SWW at xiphoid depth than DLW at self-selected speed (SMD: -1.27; 95%CI: -2.42 to -0.11; $p = 0.03$; I^2 : 79%; 60.4 ± 2.6 vs. $63.7 \pm 1.9\%$) (Figure 13).

Figure 13 - Meta-analysis of duty factor (%) at self-selected speed (xiphoid depth vs. dry land). Standard mean differences between conditions.

Joint kinematics

The hip ROM was similar in SWW at xiphoid depth and DLW at self-selected speed (SMD: -0.12; 95%CI: -0.64 to 0.39; $p = 0.64$; I^2 : 22%; 33.1 ± 3.2 vs. 33.4 ± 4.3 °) (Figure 14).

431 **Figure 14** - Meta-analysis of hip total range of motion at self-selected speed (xiphoid depth vs.
 432 dry land). Standard mean differences between conditions.

434 The knee ROM was lower in SWW at xiphoid depth than DLW at self-selected
 435 speed (SMD: -0.62; 95%CI: -1.17 to -0.06; $p = 0.03$; I^2 : 27%; 55.6 ± 7.9 vs. 59.0 ± 6.6
 436 °) (Figure 15).

437

438 **Figure 15** - Meta-analysis of knee total range of motion at self-selected speed (xiphoid depth
 439 vs. dry land). Standard mean differences between conditions.

441

442 The ankle ROM was similar in SWW at xiphoid depth than DLW at self-
 443 selected speed (SMD: -0.84; 95%CI: -2.15 to 0.47; $p = 0.31$; I^2 : 84%; 25.9 ± 7.4 vs.
 444 28.3 ± 3.9 °) (Figure 16).

445

446

447 **Figure 16** - Meta-analysis of ankle total range of motion at self-selected speed (xiphoid depth
448 vs. dry land). Standard mean differences between conditions.

450

451 *Heart rate*

452 The HR was higher in SWW at xiphoid depth than DLW at even walking speed
453 (SMD: 2.10; 95%CI: 1.18 to 3.02; $p < 0.01$; I^2 : 91%; 127.9 ± 24.1 vs. 96.3 ± 18.1 bpm)
454 (Figure 17).

455

456 **Figure 17** - Meta-analysis of heart rate at even walking speed (xiphoid depth vs. dry land).
457 Standard mean differences between walking in the same speed (1.03 ± 0.38 m/s).

The HR was higher in SWW at waist depth than DLW at even walking speed (SMD: 3.22; 95%CI: 2.14 to 4.31; $p < 0.01$; I^2 : 90%; 111.2 ± 21.1 vs. 91.1 ± 12.6 bpm) (Figure 18).

Figure 1 - Meta-analysis of heart rate at even walking speed (waist depth vs. dry land). Standard mean differences between walking in the same speed (1.06 ± 0.23 m/s).

Rating of perceived exertion

The RPE for breathing (6 to 20 scale) was higher in SWW than in DLW at both xiphoid depths (SMD: 1.21; 95%CI: 0.60 to 1.82; $p < 0.01$; I^2 : 62%; 11 ± 1 vs. 10 ± 1) (Figure 19) and waist depths (SMD: 0.83; 95%CI: 0.34 to 1.32; $p < 0.01$; I^2 : 41%; 11 ± 2 vs. 9 ± 1) (Figure 20) at even walking speed.

479 **Figure 19** - Meta-analysis of rating of perceived exertion for breathing at even walking speed
 480 (xiphoid depth vs. dry land). Standard mean differences between walking in the same speed
 481 (1.17 ± 0.32 m/s).

483

484 **Figure 20** - Meta-analysis of rating of perceived exertion for breathing at even walking speed
 485 (waist depth vs. dry land). Standard mean differences between walking in the same speed
 486 (1.11 ± 0.23 m/s).

488

489 The RPE for lower limbs (6 to 20 scale) was higher in SWW at xiphoid depth
 490 than DLW at even walking speed (SMD: 2.61; 95%CI: 1.42 to 3.79; $p < 0.01$; I^2 : 84%;
 491 11 ± 2 vs. 10 ± 1) (Figure 21).

492

Figure 21 - Meta-analysis of rating of perceived exertion for lower limb at fixed speed (xiphoid depth vs. dry land). Standard mean differences between walking in the same speed (1.17 ± 0.32 m/s).

Ground reaction forces

The peak of vertical ground reaction force (peak of V-GRF) (N/body weight) was lower in SWW at xiphoid depth than DLW at self-selected speed (SMD: -1.68; 95%CI: -2.45 to -0.90; $p < 0.01$; I^2 : 6%; 1.02 ± 0.01 vs. 1.20 ± 0.11 N/body weight) (Figure 22). Likewise, the rate of force development (body weight/s) was lower in SWW at xiphoid depth than DLW at self-selected speed (SMD: -2.54; 95%CI: -3.41 to -1.66; $p < 0.01$; I^2 : 0%; 4.55 ± 1.20 vs. 9.20 ± 1.56 body weight/s) (Figure 23).

512 **Figure 22** - Meta-analysis of peak vertical ground reaction force (N/body weight) during
 513 walking at self-selected speed (xiphoid depth vs. dry land). Standard mean differences
 514 between conditions.

516

517 **Figure 23** - Meta-analysis of rate of force development (body weight/s) during walking at self-
 518 selected speed (xiphoid depth vs. dry land). Standard mean differences between conditions.

520

521 *Muscular activity*

522 All 10 studies (3, 4, 38, 40, 48, 49, 51, 53, 54, 67) that analyzed EMG, monitored
 523 lower limb EMG, and 3 (3, 4, 49) analyzed trunk EMG. Two studies (48, 67) have
 524 compared the same walking speed (0.67 and 0.66 m/s, respectively) between water
 525 and dry land, and 7 studies (3, 4, 38, 40, 51, 53, 54) have compared the same self-
 526 selected walking condition between water and dry land. None meta-analysis was
 527 performed with EMG due to the heterogeneity of data presentation. Details about the

EMG findings of each study are described below and in Table 3. Only the Miyoshi et al. (51) study is not detailed due to the lack of information.

Masumoto et al. (48) have found higher activity at xiphoid depth in comparison to dry land of vastus medialis (VM), rectus femoris (RF), (long head) biceps femoris (BF), and gastrocnemius lateralis (GL), and similar activity for tibialis anterior (TA) at 0.67 m/s. Likewise, Shono et al. (67) comparing also xiphoid depth with dry land walking at 0.66 m/s observed in water higher activity VM, BF and TA, and similar activity for RF and gastrocnemius medialis (GM).

At self-selected speed conditions, Kotani et al. (40) found at 0.5 m depth water walking in comparison to dry land higher EMG activity in water for RF, BF, TA and GM, and similar EMG activity for vastus lateralis (VL) and gluteus medius (GIMed). Nakazawa et al. (54) found at 1.0 m depth water walking in comparison to dry land higher EMG activity for gluteus maximus, BF and tensor fascia latae (TFL), and similar EMG activity for RF, VL, TA, and soleus (SOL). Kaneda et al. (38) found at 1.1 depth water walking in comparison to dry land lower EMG activity in water for SOL, and similar EMG activity for VL, RF, BF, TA, GM. Miyoshi et al. (53) found at axillar depth similar activity of RF and TA, and higher activity in water for BF and GM.

Masumoto et al. (49) compared the EMG activity of RA, paraspinal (Psp), GIMed, RF, VM, BF lateral head, TA, and GL during walking in water at xiphoid depth and in dry land at slow, moderate and hard intensity (0.5 vs 1.0; 0.67 vs. 1.33; 0.83 vs. 1.67 m/s, respectively). The water condition was evaluated without and with addition of a water flow at subject's chest in opposite sense of walking speed. At slow intensity, all muscles presented lower activity in water. At moderate intensity, only TA presented similar activity in water and dry land. At hard intensity, only BF and TA presented similar activities in water and dry land. With the addition of water flow in opposite sense of walking speed, the BF have had higher activity with flow in comparison to without flow condition at slow intensity.

556 **Table 3** - Summary of muscular activity results.

Study	Depth	Walking speed	Muscle												
			Psp	RA	GIMax	GIMed	TFL	RF	VL	VM	BF	TA	GM	GL	SOL
Barela & Duarte (2008)	Xiphoid	SSS	↑ (End of contact; Swing)	↑ (Foot strike)			↑ (Swing)		↑ (Contact)		↑ (Contact)	↑ (Swing)	=		
Barela et al. (2006)	Xiphoid	SSS	↑ (End of contact; Swing)	↑ (Foot strike)			↑ (Swing)		↑ (Contact)		↑ (Contact)	↑ (Swing)	=		
Kaneda et al. (2007)	1.1 m	SSS						=	=		=	=	=		↓
Kotani et al. (2009)	0.5 m	SSS				=		↑	=		↑	↑	↑		
Masumoto et al. (2004)	Xiphoid	Slow (0.5 vs. 1.0 m/s)	↓	↓		↓		↓		↓	↓	↓		↓	

		Moderate (0.67 vs. 1.33 m/s)	↓	↓	↓	↓	↓	↓	=	↓
		Hard (0.83 vs. 1.67 m/s)	↓	↓	↓	↓	↓	=	=	↓
Masumoto et al. (2008)	Xiphoid	0.67 m/s				↑	↑	↑	=	↑
Miyoshi et al. (2004)	Axillar	SSS				=		↑	=	↑
Nakazawa et al. (1994)	1.0 m	SSS		↑	↑	=	=	↑	=	=
Shono et al. (2007)	Xiphoid	0.66 m/s				=	↑	↑	↑	=

557 The comparisons of muscular activity behavior are between shallow water walking in relation to dry land walking. .BF: *biceps femoris*;
558 GL: *gastrocnemius lateralis*; GIMax: *gluteus maximus*; GIMed: *gluteus medius*; GM: *gastrocnemius medialis*; Psp: *paraspinal*; RA: *rectus*
559 *abdominis*; RF: *rectus femoris*; SOL: *soleus*; SSS: comfortable self-selected speed; TA: *tibialis anterior*; TFL: *tensor fasciae latae*; VL:
560 *vastus lateralis*; VM: *vastus medialis*.

4. Discussion

The purpose of our study was to employ a systematic review of physiologic, spatiotemporal, angular, kinetic, and neuromuscular parameters of SWW in different depths performed by healthy adults and elderly. We intended, therefore, to analyze organismal physiologic variables, particularly energy expenditure, and possible biomechanical determinants involved in the SWW. The main findings (Figure 24) are that energy expenditure (PMet and C), HR and RPE are increased at both xiphoid and waist depths in comparison to DLW at even walking speed. While at self-selected speed condition there is a reduction at walking speed, stride length, stride frequency, duty factor, and ground reaction forces in SWW at xiphoid depth in comparison to DLW. Our study updates the literature review in comparison to Heywood et al (33) and Denning et al. (18) studies, and also, to our knowledge, this is the first systematic review to develop a meta-analysis comparing walking in different shallow water depths and in dry land.

Figure 24 - Summary of meta-analysis results.

Even walking speed	Self-selected walking speed
<ul style="list-style-type: none"> Metabolic Power (Xiphoid, Waist) Cost of Transport (Xiphoid, Waist) Heart Rate (Xiphoid, Waist) RPE (Xiphoid, Waist)	<ul style="list-style-type: none"> Stride Duration (Xiphoid)
<ul style="list-style-type: none"> Stride Frequency (Waist)	<ul style="list-style-type: none"> ROM Hip (Xiphoid) ROM Ankle (Xiphoid)
<ul style="list-style-type: none"> Stride Frequency (Xiphoid)	<ul style="list-style-type: none"> Walking Speed (Xiphoid, Axillar) Stride Length (Xiphoid) Duty Factor (Xiphoid) ROM Knee (Xiphoid) V-GRF (Xiphoid) Rate F Development (Xiphoid)

All comparisons are made with dry land condition. F: force; ROM: range of motion; RPE: rating of perceived exertion (breathing and lower limb); V-GRF: vertical ground reaction force.

The higher physiologic demand during SWW in comparison to DLW at even walking speed could have some explanations. Firstly, one could analyze the hydrostatic force involved, and secondly, the hydrodynamic force.

The principal hydrostatic force acting during shallow water walking is the B that creates a hypogravity condition. At hypogravity there is a reduction of external mechanical work (14, 57), nevertheless, the metabolic demand does not diminish proportionally to the reduction of the mechanical demand (25, 29) or does not even diminish at all (57). Farley & McMahon (25) found a reduction of only 25% of C with a 75% reduction on gravity, while Pavei et al. (57) reported a non-statistically significant reduction of 18% in C at 0.36 and 0.16 g conditions. A possible explanation for this relatively high metabolic cost in hypogravity conditions is the importance of the mechanical energy fluctuations of the moving limbs during walking (14, 29), i.e., internal mechanical work. Nevertheless, our findings do not demonstrate a relatively small reduction, but a significant increase in energy expenditure during SWW. Which take us to the hydrodynamic approach of the SWW.

At a given speed, there is a maintenance or increase of the stride frequency at dry land hypogravity conditions with negligible DrF (14), but at SWW was observed a maintenance (waist depth) or decrease (xiphoid depth) of stride frequency at a fixed speed in comparison to DLW. Considering that the internal work is directly proportional to the stride frequency (13), one could expect that this maintenance/reduction of stride frequency would maintain/reduce the internal work, reducing the energy expenditure. The explanation of the higher physiologic demand during SWW in comparison to DLW - despite the expected reduction of both external and internal work at hypogravity – can be the hydrodynamic resistance of water due the DrF. The DrF resists to the body displacement in the fluid, generating a mechanical dissipative system, breaking down the speed of locomotion. In order to maintain a constant speed, the body needs to employ extra chemical energy in order to overcome this resistance force during SWW, leading to higher physiologic

demands (PMet, C, HR, RPE) and also modifying the spatiotemporal (stride frequency) characteristics of walking.

The HR was higher during SWW at even speed in comparison to DLW at both xiphoid and waist depths. In spite of the bradycardia effect due to water immersion in rest condition (41), the walking activity was able to develop higher HR in water than in dry land when performed at even speed. Using the formula to calculate the predicted maximal HR during immersion proposed by Kruel et al. (41), it can be seen that SWW at xiphoid (127.9 ± 24.1 vs. 96.3 ± 18.1 bpm; 77% vs. 55% of maximum HR) and at waist (111.2 ± 21.1 vs. 91.1 ± 12.6 bpm; 63% vs. 49% of maximum HR) depths demands higher absolute and relative HR levels in comparison to DLW at the even speed. This higher HR could also help to explain the higher energy expenditure found for SWW due to reverse Fick principle (9) of oxygen consumption.

The RPE for breathing was higher at both waist and xiphoid depths than in DLW at even speed. Likewise, the RPE for lower limbs during walking at even speed was higher in xiphoid depth than in dry land. This could be related to the higher energy expenditure values encountered for walking at same speed in water in comparison to dry land. Also, the respiratory mechanical work is increased due to increased airways resistance and reduced pulmonary volume in aquatic immersion (1), probably affecting the breathing sensation.

During the self-selected condition, our results demonstrated a reduction of the comfortable (xiphoid and axillar) and fast (axillar) self-selected walking speed in SWW in comparison to DLW. In accordance with the principle of dynamic similarity, at hypogravity conditions the optimal walking speed is lower in comparison to Earth gravity, considering that the pendulum mechanism operates optimally at lower speeds of walking at lower gravity (45, 50, 58, 69). To maintain a constant Froude number of 0.25 - proportional to the optimal speed of walking – at hypogravity, the speed is reduced by a factor of the squared root from the relative gravity

($v_{new\ condition} = v_{Earth}(\sqrt{g_{new\ condition}/g_{Earth}})$). Therefore, the self-selected speed of walking, considered close to the optimal speed (64), would also be expected to be reduced in hypogravity conditions.

The lower speed of walking in water in comparison to dry land could also be explained by a hydrodynamic approach. The DrF resists to the body displacement through the fluid and has a squared relation with the speed of displacement (71). Higher speed of walking causes higher DrF, inducing higher demands over the musculoskeletal system to sustain the motor activity. Masumoto et al. (46) found higher values of energy expenditure when walking at xiphoid depth in underwater treadmill with the addition of water flow on subject chest in opposite sense to walking speed, in comparison to a condition without the water flow. Therefore, at conditions that the subject is oriented to selected the most comfortable speed of walking, it is expected lower speeds in water in comparison to dry land. This pattern seems to be independent of age (3, 4), gender (15), and water depth (4, 51, 53).

At self-selected speed condition, the SWW at xiphoid depth presented lower stride length (SMD = -1.38; 1.09 ± 0.18 vs. 1.28 ± 0.09 m) and higher stride duration (SMD: 6.40; 2.4 ± 0.4 vs. 1.0 ± 0.1 s) in comparison to DLW. Observing the higher SMD for stride duration, it seems that the walking speed reduction in water is mainly due to the temporal rather than spatial characteristics of gait cycle. This fact can also be explained by the hydrodynamic characteristics of the water walking: the reduction of walking self-selected speed in water seems to be caused mainly by the reduced angular velocity of the lower limb (17, 56) which will increment the stride period, more than due to reduction in the total foot excursion during the stride (stride length).

The lower limb ROM at self-selected speed showed similar values for hip and ankle, while knee presented lower values in SWW at xiphoid depth (SMD: -0.62; 55.6 ± 7.9 vs. 59.0 ± 6.6 °) in comparison to DLW. At first, these data suggest a somehow similar lower limb angular pattern for walking at xiphoid and dry land self-selected walking. Nevertheless, considering the reduced stride length in the xiphoid depth in comparison to dry land, one could expect reduced ROM at xiphoid condition. Modeling the lower limb as a pendulum with constant radius, a lower linear displacement (arch length) will cause a lower angular displacement; but this is not what happened for hip and ankle joints. So, it can be interpreted that although these joints presented similar absolute angular displacement at xiphoid depth and dry land, they presented higher relative angular displacement at xiphoid depth. The same

could be said about the knee, considering the higher SMD size for stride length (-1.38) than for knee ROM (-0.62).

The lower limb angular displacement adaptations during SWW can be a kinematic strategy to minimize the effects of DrF resistance. Considering the DrF dependence on the projected frontal area, the locomotor system seems to manage the DrF resistance by controlling the relative angular displacement of lower limb joints. In this way, the higher relative angular displacement could be a strategy to reduce the projected frontal area, considering the more flexed positions of hip (3, 10) and knee (3, 10, 17) during stride cycle. On the other side, the DrF dependence on speed seems to be controlled by the angular velocity. Despite the lower stride length during water walking, the similar absolute angular displacement associated with higher stride period leads to diminished peak angular velocities (17, 56).

The peak V-GRF and the rate of force development during walking at self-selected speed was lower in SWW at xiphoid depth than in DLW. The pattern of V-GRF curve during SWW was flatter in comparison to DLW (3, 4) at self-selected speed. The peak V-GRF was lower in water in comparison to dry land, even if the V-GRF was normalized by the body weight (11, 53, 54, 56) or by the apparent body weight in immersion condition (3, 4). This could be understood by the relation of peak V-GRF with both immersion ratio (ratio between water depth and stature) and speed of walking (32), considering the B effects and lower self-selected speed in water. The anterior-posterior ground reaction force curve during water walking assumed a predominant positive pattern, different from the negative-positive pattern of dry land walking (3, 4, 53, 56). This monophasic anterior-posterior ground reaction force curve is justified by the authors as a kinetic strategy to maintain a constant walking speed and overcome the DrF horizontal resistance of water.

The muscular activity findings are not conclusive, but it can be observed a pattern of higher activity in SWW of lower limb in the studies that compared the same speed (48, 67) and self-selected speed (40, 53, 54) of walking in water and in dry land, what could be related to the necessity of overcome the DrF resistance in order to move the limb during gait cycle. The only study that reported a pattern of muscular activity reduction in water was of Masumoto et al. (49), but this study compared the

SWW at half of the speed of the DLW at treadmill. Despite other studies compared self-selected speed between water and dry land – expected to be lower in water -, they analyzed shallow water walking on the pool floor, and not on an underwater treadmill (3, 4, 38, 40, 53, 54). The underwater treadmill condition can be a source of influence on the neuromuscular activation during walking, due to the reduced body center of mass horizontal displacement in comparison to the pool floor walking, that can reduce the force production demand from the neuromuscular system. And the other studies that investigated underwater treadmill have compared the muscular activity in SWW at same speed with DLW treadmill (48, 67). Also, at self-selected (3, 4, 40, 53, 54) and even (48, 67) speed of walking, BF activation was higher in SWW in comparison to DLW. This finding can be attributed to higher extensor hip moment observed during SWW, related to the need to overcome the DrF resistance (51–53).

Limitations

The limitations of this systematic review are related to the search terms choice and to language restriction, that could have left out others studies eligible to inclusion. The limitations associated with the analyses of the included studies are related to the methodological heterogeneity between studies, as the different depth method determination and speeds performed. Of all 40 included studies, only 7 (2, 27, 31, 37, 42, 54, 61) have used more than one depth as comparator to dry land, complicating a better understanding from the depth level influence on the walking parameters. The lack of information of the data results also have limited the inclusion of more studies in the meta-analysis.

Future directions

Some suggestions can be made from the results of the present systematic review for future studies investigating the acute effects of SWW. It can be suggested the execution of studies that investigate more than one shallow water depth, in order

to provide a better understand of the influence of hydrostatic and hydrodynamic forces involved during SWW on metabolic cost. For example, Kuliukas et al. (42) have found at waist depth walking higher values of C at low (<0.2 m/s) and high (>0.7 m/s) speeds, with the minimum C during walking at intermediate speeds (0.3 to 0.7 m/s). To our knowledge, this is the first study to demonstrate this C behavior during SWW. Nevertheless, remains the question if this U-shaped curve appears during walking in other depths.

A deeper exploration of the behavior of spatiotemporal (self-selected speed, stride frequency, stride length), lower limb angular parameters and neuromuscular activity during shallow water walking in other depths than xiphoid is recommended. The investigation of neuromuscular activity in different depths can help to explain the higher energy expenditure at organismal level.

The analysis of these variables on a more thorough depth gradation could enhance the exercise and therapeutic prescription to a variety of healthy conditions and different populations, and help to understand if these alterations can maximize gains in metabolic economy and gait biomechanics after long-term SWW intervention.

5. Conclusion

The SSW is a locomotion condition strongly influenced by the hydrostatic and hydrodynamic forces due water immersion. Our systematic review found higher physiologic demand (energy expenditure, HR, RPE) in SWW at waist and xiphoid depths in comparison to DLW at even walking speed. While at self-selected speed conditions was found lower speed, lower stride length, and lower stride frequency in SWW at xiphoid in comparison to DLW. All ground reaction forces were reduced during SSW, and muscular activity seems to be higher in water at even walking speed than dry land, or during floor walking at self-selected speed.

We recommend future studies exploring these physiological and biomechanical variables during SSW in other depths than xiphoid, in order to investigate if the neuromuscular activity can help to explain the higher energy

expenditure at organismal level. Also, we indicate future studies that analyze if these alterations can maximize gains in metabolic economy and gait biomechanics after long-term SWW intervention.

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