Gait & Posture 48 (2016) 120–130

Contents lists available at ScienceDirect

Gait & Posture

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

Review

Spatiotemporal, kinematic, force and muscle activation outcomes during gait and functional exercise in water compared to on land: A systematic review☆

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ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form 27 April 2016
Accepted 28 April 2016

Keywords:
Aquatic exercise
Biomechanics
Hydrotherapy

ABSTRACT

Background: Exercises replicating functional activities are commonly used in aquatic rehabilitation although it is not clear how the movement characteristics differ between the two environments. A systematic review was completed in order to compare the biomechanics of gait, closed kinetic chain and plyometric exercise when performed in water and on land.

Methods: Databases including MEDLINE, CINAHL, SPORTDiscus, Embase and the Cochrane library were searched. Studies were included where a functional lower limb activity was performed in water and on land with the same instructions. Standardized mean differences (SMD) and 95% confidence intervals were calculated for spatiotemporal, kinematic, force and muscle activation outcomes.

Findings: 28 studies included walking or running (19 studies), stationary running (three), closed kinetic chain exercise (two), plyometric exercise (three) and timed-up and go (one). Very large effect sizes showed self-selected speed of walking (SMD >4.66) and vertical ground reaction forces (VGRF) (SMD >1.91) in water were less than on land, however, lower limb range of movement and muscle activity were similar. VGRF in plyometric exercise was lower in water when landing but more similar between the two environments in propulsion. Maximal speed of movement for walking and stationary running was lower in water compared to on land (SMD > 3.05), however was similar in propulsion in plyometric exercise.

Interpretation: Drag forces may contribute to lower self-selected speed of walking. Monitoring speed of movement in water assists in determining the potential advantages or limitations of aquatic exercise and the task specificity to land-based function.

1. Introduction

The aquatic environment provides an alternative option for active rehabilitation [6]. Evidence suggests that aquatic exercise is as effective as land-based exercise in changing function and mobility [1–3], quality of life [1] dynamic balance [2] and pain [4,5] in a range of musculoskeletal conditions, although the characteristics of the most beneficial aquatic program is unclear [1]. With the growing popularity of therapeutic aquatic exercise, understanding the environment is critical to the prescription of exercise in water [6].

Understanding the aquatic environment relates to the hydrostatic and hydrodynamic theories of buoyancy and drag and how these forces influence movement in water. In considering the clinical applications of these concepts in exercise, buoyancy and drag force can be modified by different characteristics of the environment, individual or task. Buoyancy is influenced by the relative density and volume of the body immersed [7]. Greater depth of immersion increases the upthrust effect for weight-bearing exercise [6]. Force from buoyancy is also specific to the direction of movement, with upwards movements being assisted and downwards movements resisted [7,8]. In contrast, drag force

☆ PROSPERO registration number: CRD42014015544.

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http://dx.doi.org/10.1016/j.gaitpost.2016.04.033
0966-6362/

primarily is determined by the speed of the movement and frontal area of the moving part with greater speed and surface area increasing resistance to movement [7,9].

Maximizing the use of drag and buoyancy and refining program content to increase the potential therapeutic benefits is a key component of aquatic exercise prescription [10]. A more comprehensive understanding of movement in water is required to determine whether functional lower limb exercise, such as gait, squats or sit to stand, has enough similar characteristics to their land-based counterparts to justify task-based training. Greater clarity in specificity of movement and load could also lead to improved exercise prescription and outcomes in aquatic therapy.

Despite the fundamental physics principles being well established, there is limited empirical biomechanical evidence evaluating the movement characteristics of aquatic exercise compared to land based exercise. With limited consensus conclusions from individual studies and outstanding questions related to understanding the aquatic environment [11–13], a systematic review to describe how movement differs between water and land could provide guidance for more precise exercise prescription. The aims of this systematic review therefore were to: (1) analyze studies comparing similar functional lower limb exercise including gait, closed kinetic chain and plyometric exercise in water and on land for spatiotemporal, kinematic, force and muscle activation outcomes, and (2) to determine how the instructions on speed of movement influence outcomes for these variables.

2. Methods

2.1. Search strategy

The Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) guidelines [14] were followed using keywords and subject headings related to aquatic exercise and movement analysis outcomes. Combinations of the following main search terms defined the systematic review conceptual framework: hydrotherapy, aquatic exercise, water exercise, walking in water; and the outcomes of interest: biomechanics, electromyography, kinematics, kinetics, cadence, stride length, stance time, ground reaction force, rate of force development. A search of five databases including MEDLINE, CINAHL, SPORTDiscus, Embase and the Cochrane library was conducted from inception until November 2014. For further search strategy detail see Appendix 1. Reference checking and citation tracking of the included articles and other review papers in aquatic exercise uncovered sources in more obscure locations [15]. The proposed systematic review details were registered in PROSPERO (CRD42014015544).

2.2. Selection criteria and process

Studies were included where:

1) Completion of functional lower limb exercise on land was compared to the same exercise in water (for example, gait, squat or jump).
2) Movement was compared between land and water on the following outcomes: spatiotemporal parameters (speed or time to complete the exercise, stride or step length, stance time or support phase time), kinematics (lower limb joint range of movement), forces (direction and peak vertical or anteroposterior ground reaction force, rate of force development) or muscle activation (electromyography).
3) Instructions for the speed of movement were the same for both conditions.
4) Either in healthy individuals or those with musculoskeletal conditions.
5) Publication was in full-text in peer-reviewed journals in the English language.

If two papers reported data for the same participant group but investigated different exercises or reported different outcomes then all studies were included.

Studies were excluded if the movements were fundamentally different between water and land, for example, no studies examining deep water running were included as it is non-weight bearing and therefore does not have a land-based equivalent. Studies in participants with neurological or cardiorespiratory conditions were excluded.

Two reviewers (SH, JM) independently assessed the title and abstract of each article retrieved from the search of databases using a standardized checklist of the pre-determined inclusion and exclusion criteria. After this screening process the full text articles not excluded initially were then reviewed for final inclusion using the same criteria.

2.3. Data extraction

Two reviewers (SH, JM) independently extracted data from the eligible studies including relevant details of participants, movement, methodology and outcomes. If reviewers authored one of the papers, a third reviewer (PG) completed both data extraction and quality assessment. If data was only displayed graphically or if no means or standard deviations were reported, contact was made with corresponding authors to request numerical data. If this data was not received then the available results from the study were extracted.

2.4. Quality and risk of bias assessment

A checklist based on Downs and Black [16] was used to assess the quality and risk of bias of each included study independently by two raters (SH, JM). Discrepancies were resolved by discussion and consultation with a third reviewer (PG) if needed.

2.5. Data analysis

Standardized mean differences (SMDs) with 95% confidence intervals (CIs) were calculated comparing the outcomes between the two environments as the main quantitative finding of the review [17] using Review Manager analysis software Version 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark) [18]. A meta-analysis was not appropriate given the heterogeneity and range of functional exercises investigated across the different studies [19,20]. Instead SMD and CI were grouped together within one forest plot to present findings for similar outcome domains. To analyze trends, forest plot development occurred only when there was numerical data available for two or more studies reporting the same outcome. Narrative reporting described single studies unable to be grouped or mean results when effect sizes could not be calculated.

Movement instructions varied across studies. Results are presented related to the speed of the exercise, sub-classified into either self-selected speed (participants asked to choose their own comfortable speed both in water and on land), matched speed (participants instructed to move at a specified pace, the same in water and on land) or maximal speed (participants asked to perform the exercise at maximal speed or effort). For studies with more than one matched speed the mid-range speed or a speed closest to a similar speed in another study included in the same forest plot was chosen.

For studies investigating movements at more than one depth in the aquatic environment, the depth most similar to another study in the same forest plot was chosen. Speed and time taken to complete the activity were combined in the same forest plot (with means multiplied by – 1 for time taken to complete the activity to ensure all scales pointed in the same direction) [19].

Average and peak integrated or normalized muscle activity were the most commonly reported electromyography variables and were therefore analyzed with erector spinae, rectus abdominus, quadriceps, hamstrings, calf and tibialis anterior as the muscle groups reported in three or more studies. For studies that divided mean EMG readings into stance and swing phase of gait, the phase of the greatest activity on land as identified by Winter [21] was analyzed. Missing standard deviations were imputed from other available data where possible, for example, confidence intervals, t values or standard errors [20]. The means and standard deviations of data for gender subgroups were combined [20]. Effect size thresholds were classified as a SMD of small (0.2), medium (0.5), large (0.8) and very large effect (1.3) [22] with non-significant results indicated when the 95% CI includes zero [23].

3. Results

3.1. Selection of studies

28 studies were included in the review after an initial yield of 583 (Fig. 1).

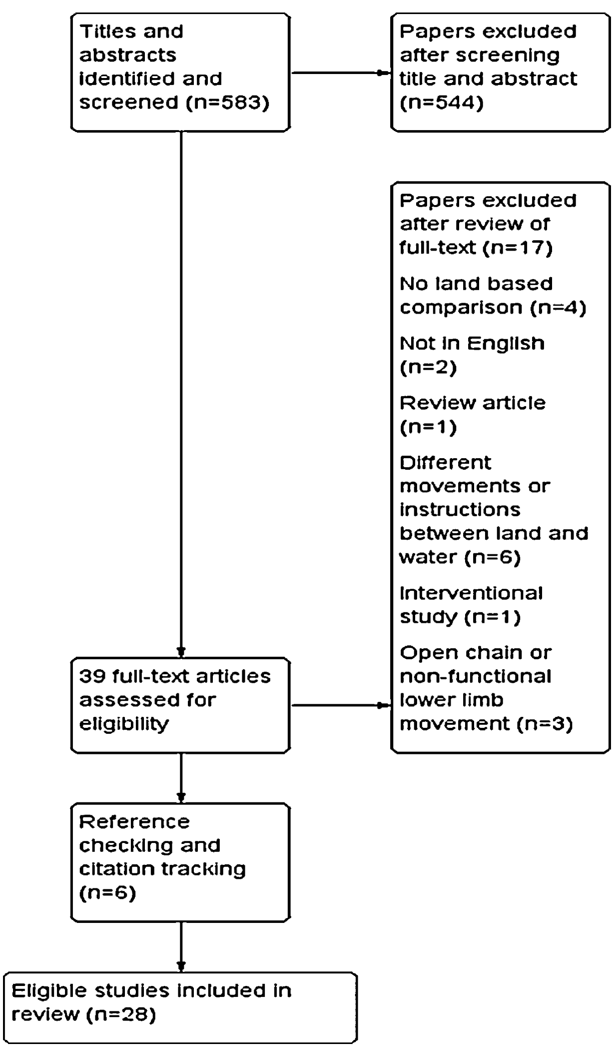

Fig. 1. PRISMA flowchart of inclusion procedure.

3.2. Study characteristics

Of the 28 included studies (Table 1), 23 studies investigated adults with a mean age between 18 and 60 years, two studies investigated younger participants with a mean age of 16 [24,25] and three studies included older participants with a mean age greater than 60 years [26–28]. No studies assessed people with musculoskeletal disease.

3.2.1. Exercises

A variety of functional movements were analyzed including propulsive walking overground or across the pool [26,27,29–40], walking on a treadmill [28,41–43], running on a treadmill [41,43,44], stationary running or running on the spot [45–47], sit to stand [48], single leg squat [49], timed-up and go [50] and hopping or jumping [24,25,51].

3.2.2. Instructions related to speed of movement

Of the 28 papers, in 13 studies participants were asked to move at self-selected or comfortable speed and these were all overground walking studies. In two of these studies, participants were also measured during maximal speed of walking [31,33]. Six studies investigated walking or running at the same prescribed speed in water as on land [28,40–44], two studies measured stationary running [45,47] and two studies measured closed kinetic chain exercise including sit to stand [48] or single leg squat [49]. All plyometric studies were performed at maximal speed [24,25,51].

3.2.3. Outcomes

20 studies reported on spatiotemporal outcomes, nine described kinematic outcomes, 11 measured forces and 15 reported EMG. Three studies measured outcomes across all of these domains [26,29,35].

3.2.4. Depth of immersion

Aquatic exercises were most commonly investigated at chest depth (18 of 28 studies), either immersed to the xiphisternum or the axilla. The other studies specified waist, umbilicus or thigh depth of immersion or a fixed depth between 0.4 and 1.3 m. Five studies investigated exercises at multiple depths [31,38,40,43,49].

3.3. Quality assessment

All studies specified aims or objectives (Table 2). Clear description of findings and outcomes were reported inconsistently across studies. Two of the 28 studies reported a power calculation [26,29].

3.4. Outcomes

3.4.1. Spatiotemporal outcomes

The forest plot (Fig. 2) indicates that, at self-selected speed, consistent and very large effect sizes (SMD <-4.66) exist for walking slower and taking shorter step lengths (SMD <-0.89) in water compared to on land. There were inconsistent effect sizes in the forest plot for support phase duration at self-selected speed of walking and Nakazawa [38] reported support phase to be longer on average in water compared to on land.

Cadence, investigated in only one study at self-selected speed of walking, showed a very large effect for lower cadence in water compared to on land (SMD 11.50, 95% CI: -16.19, -6.81) [27]. There was no consistent trend in the effect sizes for cadence at matched speeds (Fig. 2.3).

There was no consistent trend in the effect sizes for support phase duration (Fig. 2.4) when participants were asked to move at the same speed in both environments.

Table 1
Overview of studies.

Study	Exercise	*N* (male)	Mean age (SD)	Instructions related to speed			Depth	Outcomes			
				Self-selected	Matched	Maximal		ST	KIN	FORCE	EMG
Barela 2006	Walk	10 (4)	29 (6)	✓			Xiphi	✓	✓	✓	✓
Barela 2008	Walk	10 (6)	70 (6)	✓			Xiphi	✓	✓	✓	✓
Carneiro 2012	Walk	22 (11)	24.6 (2.6)	✓			Xiphi	✓	✓	✓	
Chevutschi 2007	Walk	7 (0)	22.7 (2.5)	✓			Umb	✓			✓
Chevutschi 2009	Walk	31 (16)	F;22.8 (2.1); M;22.8 (1.8)	✓		✓	Hip Xiphi	✓			
Degani 2006	Walk	8 (4)	62.5 (nr)	✓			Xiphi	✓			
Fowler-Horne 2000	Walk	10 (7)	26.9 (nr)	✓		✓	1.2 m	✓			
Kaneda 2007	Walk	9 (9)	24.9 (2.2)	✓			1.1 m				✓
Miyoshi 2003	Walk	8 (8)	23 (2.3)	✓			Axilla		✓		
Miyoshi 2004	Walk	15 (15)	22.8 (4.5)	✓			Axilla	✓	✓	✓	✓
Miyoshi 2005	Walk	16 (12)	22.3 (2.7)	✓			Axilla	✓			✓
Nakazawa 1994	Walk	6 (4)	25.5 (2.3)	✓			0.4 m 0.7 m 1.0 m 1.2 m	✓		✓	✓
Orselli 2011	Walk	10 (4)	24 (3)	✓			Xiphi	✓	✓	✓	
Kato 2002	Walk (Tr)	6 (6)	19.8 (1.3)		0.4 m/s 0.6 m/s 0.8 m/s		Waist	✓			✓
Petrofsky 2002	Walk	6 (3)	24–46[a]		0.3 m/s 0.4 m/s		0.9 1.2		✓		✓
Shono 2007	Walk (Tr)	8 (0)	61.4 (3.9)		0.7 m/s		Xiphi	✓	✓		
Kato 2001	Walk & run (Tr)	6 (6)	19.8 (1.3)		0.6 m/s 1.1 m/s 1.7 m/s 2.2 m/s 2.8 m/s 3.3 m/s		Waist	✓	✓		
Pohl 2003	Walk & run (Tr)	6 (6)	23.2 (2.9)		1.1 m/s 1.9 m/s		Thigh Waist	✓			
Silvers 2014	Run (Tr)	12 (12)	25.8 (5)		2.9 m/s 3.4 m/s 3.8 m/s		Xiphi				✓
Alberton 2011	Stationary run	12 (0)	22.3 (0.6)		60 bpm 80 bpm 100 bpm	✓	Xiphi	✓			✓
de Brito Fontana 2012	Stationary run	22 (11)	F;23 (2.5); M; 24 (3)		90 st/min 110 st/min 130 st/min		Xiphi			✓	
Alberton 2013	Stationary run	15 (0)	23.2 (2)			✓	Xiphi	✓		✓	
Cuesta-Vargas 2013a	Sit to stand	10 (5)	22 (3.1)		20 bpm		Xiphi				✓
Fuller 1999	Squat	51 (28)	18–61		30 bpm		Waist Chest				✓
Cuesta-Vargas 2013b	TUG	10 (5)	22 (3.1)			✓	1.0 m				✓
Triplett 2009	Plyometric	12 (0)	16 (0.7)			✓	Xiphi	✓		✓	
Colado 2010	Plyometric	12 (0)	16 (0.7)			✓	Xiphi	✓		✓	
Donoghue 2011	Plyometric	18 (0)	23 (1.9)			✓	1.3 m	✓		✓	

Abbreviations: ST = spatiotemporal; KIN = kinematic; EMG = electromyography; Tr = treadmill; bpm = beats per minute; st/min = steps per minute; EMG = electromyography; M = male; F = female; Xiphi = xiphisternum; Umb = umbilicus; m = metre.
[a] Range of ages.

For exercises performed at maximal speed, inconsistent results showed that the difference between the maximal speed in water and on land varied depending on the activity. The horizontal movement of walking resulted in a very large effect in both studies for slower maximal speed of walking in water compared to on land (SMD <-7.75). For the vertical tasks (propulsive phase of jumping and hopping) similar speeds in both environments were observed (Fig. 2.1.2).

A single study measured support phase duration for stationary running at maximal speed resulting in a very large effect size indicating shorter support phase duration in water than on land (SMD -1.60, 95% CI: -2.43, -0.76) [46].

3.4.2. Kinematic outcomes

When participants walked at self-selected speed, hip, knee and ankle range of movement were similar in the majority of the studies between the two environments (Fig. 3). In the single study measuring joint range with participants walking at the same speed in the water as on land, very large effect sizes indicated greater range of movement in water in all 3 lower limb joints (hip range SMD 2.78, 95% CI: 1.01, 4.54, knee range SMD 1.37, 95% CI: 0.06, 2.69, ankle SMD 2.76, 95% CI: 1.00, 4.52) [41]. The authors reported the mean difference in joint range between environments to be 12.5° at the hip, 6.7° at the knee and 13.6° at the ankle.

3.4.3. Force outcomes

Very large effect sizes showed vertical ground reaction force (VGRF) consistently lower in water at self-selected speed of walking in both weight acceptance and the propulsive phase of stance (SMD <-1.91) (Fig. 4.1). Miyoshi et al. [35] and Nakazawa [38] reported similar findings in walking at self-selected speed. Effect sizes for VGRF indicated lower force in water compared to on land in the majority of studies in the landing phase of plyometric exercise. In contrast, only the propulsive phase of hopping and

Table 2
Quality assessment.

Study	1. Hypothesis, aim or objective clearly described	2. Main outcomes clearly described	3. Characteristics of the patients clearly described	5. Distributions of principal confounders in each group of subjects clearly described	6. Main findings clearly described	7. Estimates of the random variability in the data for the main outcomes provided	10. Actual *p* values been reported for the main outcomes	20. Main outcome measures used accurate (valid and reliable)	27. Power calculation
Alberton 2011	Y	Y	Y	Y	Y	Y	Y	Y	Y
Alberton 2013	Y	Y	Y	Y	Y	Y	Y	Y	Y
Barela 2006	Y	Y	Y	P	Y	Y	N	Y	N
Barela 2008	Y	Y	Y	P	Y	Y	Y	Y	N
Carneiro 2012	Y	Y	Y	P	Y	Y	Y	N	N
Chevutschi 2007	Y	Y	Y	P	Y	Y	N	Y	N
Chevutschi 2009	Y	Y	Y	P	Y	Y	N	Y	N
Colado 2010	Y	Y	Y	Y	Y	Y	Y	Y	N
Cuesta-Vargas 2013a	Y	Y	N	P	Y	Y	N	Y	N
Cuesta-Vargas 2013b	Y	Y	N	P	Y	Y	Y	Y	N
Degani 2006	Y	Y	N	N	Y	Y	N	N	N
de Brito Fontana	Y	Y	Y	Y	Y	Y	Y	Y	N
Donoghue 2011	Y	Y	N	P	Y	Y	N	Y	N
Fowler-Horne 2000	Y	Y	Y	P	Y	Y	N	N	N
Fuller 1999	Y	Y	Y	P	N	N	N	Y	N
Kaneda 2007	Y	Y	N	P	N	Y	N	Y	N
Kato 2001	Y	Y	N	Y	Y	Y	N	N	N
Kato 2002	Y	Y	Y	P	N	Y	N	Y	N
Miyoshi 2003	Y	Y	Y	P	N	Y	N	Y	N
Miyoshi 2004	Y	Y	Y	P	N	Y	N	Y	N
Miyoshi 2005	Y	Y	Y	P	N	Y	N	Y	N
Nakazawa 1994	Y	Y	Y	P	N	Y	N	Y	N
Orselli 2011	Y	Y	Y	Y	Y	Y	Y	Y	N
Petrofsky 2002	Y	N	Y	P	Y	Y	N	N	N
Pohl 2003	Y	Y	Y	N	Y	Y	N	N	N
Shono 2007	Y	Y	N	Y	Y	Y	N	Y	N
Silvers 2014	Y	Y	Y	Y	Y	Y	Y	Y	N
Triplett 2009	Y	Y	Y	Y	Y	Y	N	Y	N

Abbreviations: Y = yes, P = criteria partially met, N = no.

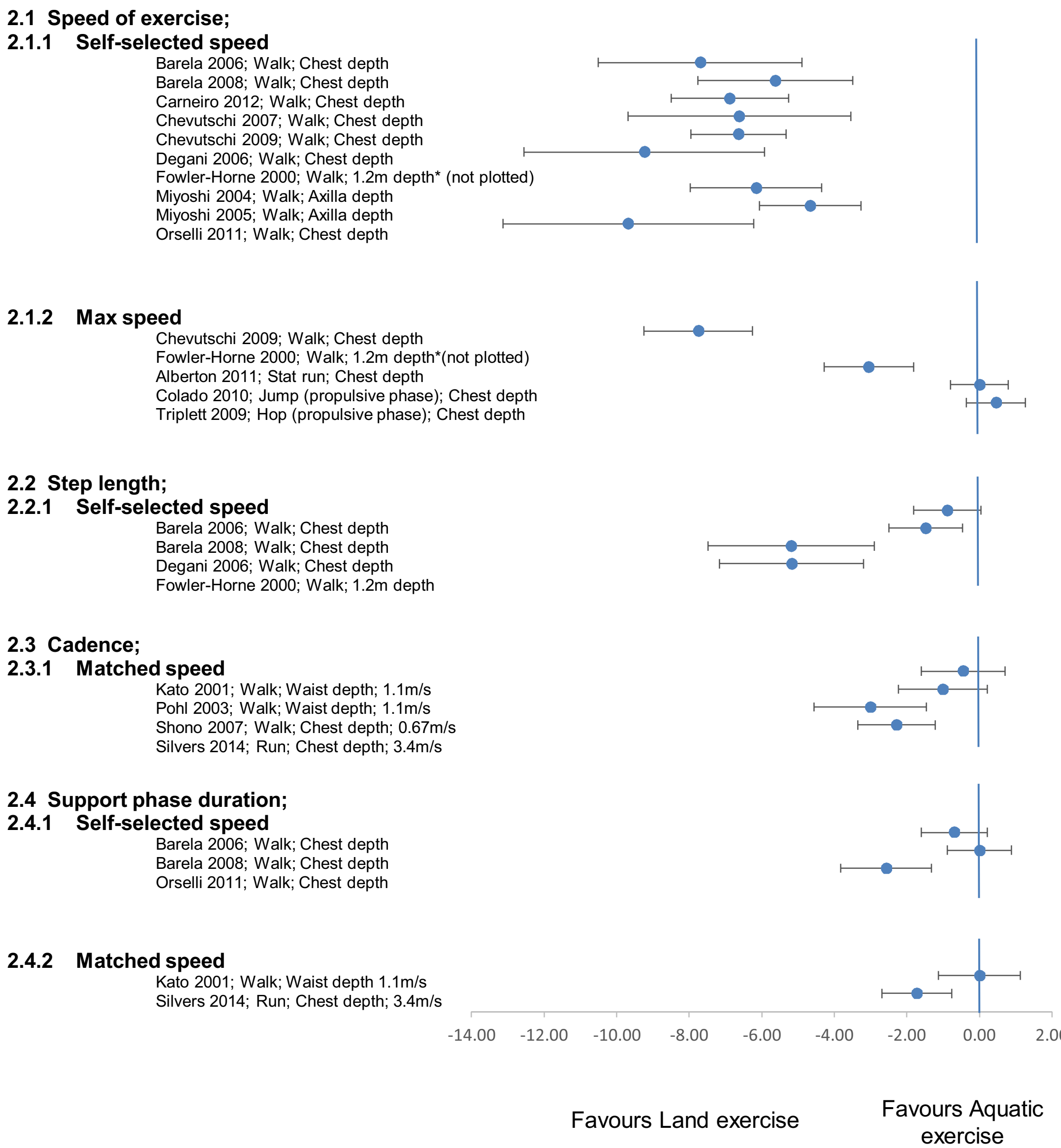

Fig. 2. Spatiotemporal outcomes. *Fowler-Horne [33] – Speed: self-selected SMD −87.27: 95% CI; −117.46, −57.08; maximal SMD −77.24: 95% CI; −103.96, −50.51; not plotted on graph as a typographical error in the reporting of standard deviations could not be discounted.

jumping demonstrated effect sizes for VGRF to be similar in the two environments or higher in water.

There was no clear trend for anteroposterior ground reaction force (APGRF) force at self-selected speed of walking between the two environments in the forest plot (Fig. 4.2). In the single studies at the other speeds, lower force on land was indicated by large effect sizes for stationary running at matched speed (SMD −0.98, 95% CI −1.61, −0.35) [47] and a very large effect size in the landing phase of hopping at maximal speed (SMD −4.55, 95% CI −6.18, −2.93) [25].

On land the profile of the AP GRF changed from an initial negative phase to a positive phase with walking, representing deceleration and then forward acceleration [21]. However AP GRF remained positive during walking in water [26,29,39] and did not display the initial negative phase.

Consistent and very large to large effect sizes indicated lower rate of force development (RFD) in water for the landing phase of plyometric exercise completed at maximal speed (SMD <−0.8) (Fig. 4.3) compared to on land. This trend was supported in a single study at matched speed in stationary running (SMD −0.72, 95% CI −1.33, −0.10) [46]. Non-significant effect sizes showed similar RFD in water and on land in the propulsive phase of jumping and hopping.

3.4.4. Muscle activation outcomes

At self-selected speed the effect sizes indicated similar average and peak muscle activity in the majority of studies and muscle groups (Figs. 5 and 6). At matched speeds the effect sizes were inconsistent, with no pattern for average muscle activity and insufficient data to identify a clear trend for peak muscle activity in water compared to on land. However, effect sizes for both average and peak muscle activity at maximal speeds typically indicated greater activity on land compared to in water.

4. Discussion

Comparing the movement characteristics of functional lower limb activities in water to on land demonstrates potential

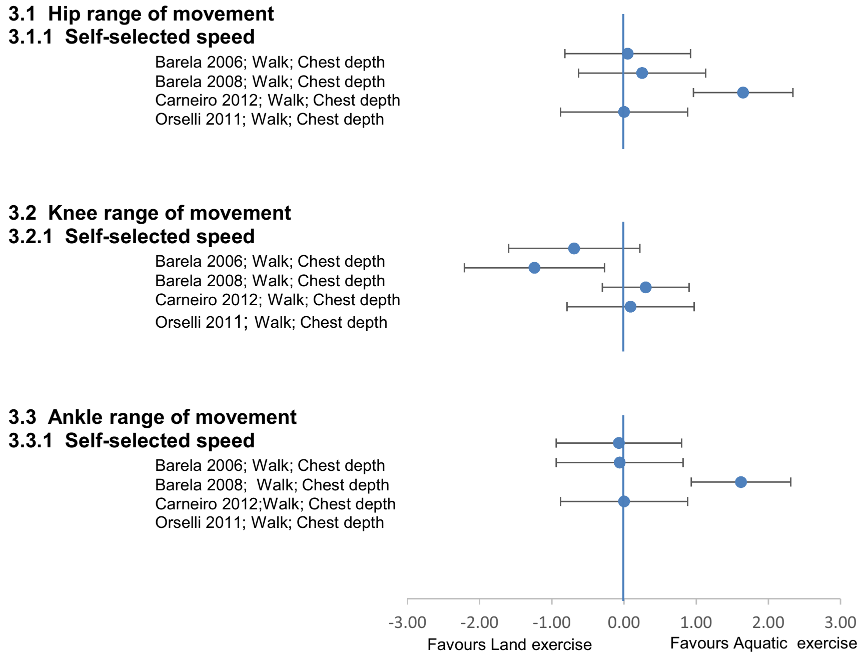

Fig. 3. Kinematic outcomes.

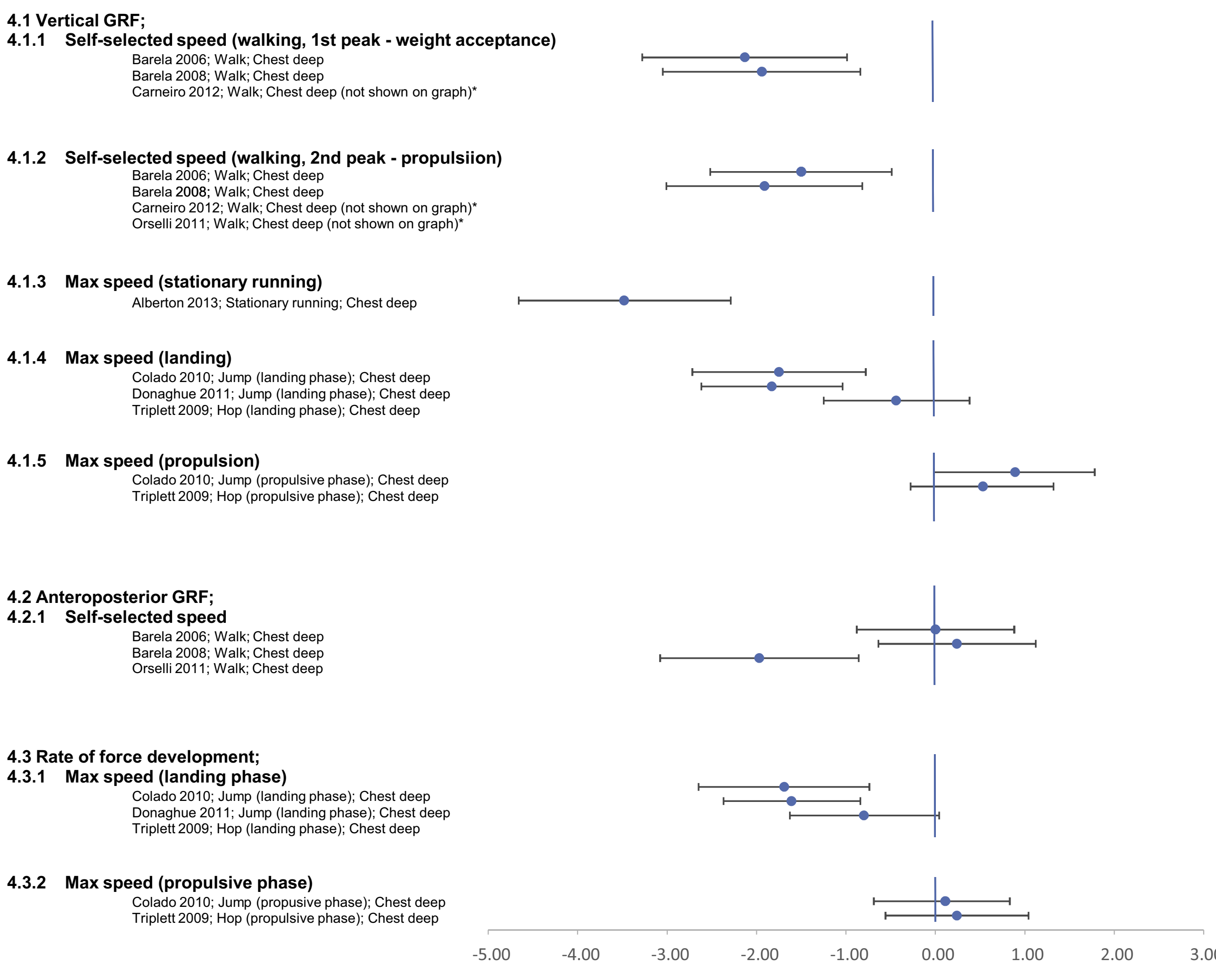

Fig. 4. Force outcomes. *Not shown on graph to allow easier comparison of results: Carnerio VGRF 1st peak SMD −12.40; 95% CI: −15.18, −9.62; VGRF 2nd peak SMD −14.64; 95% CI: −17.90, −11.38: Orselli VGRF 2nd peak SMD −15.03; 95% CI: −20.30, −9.76.

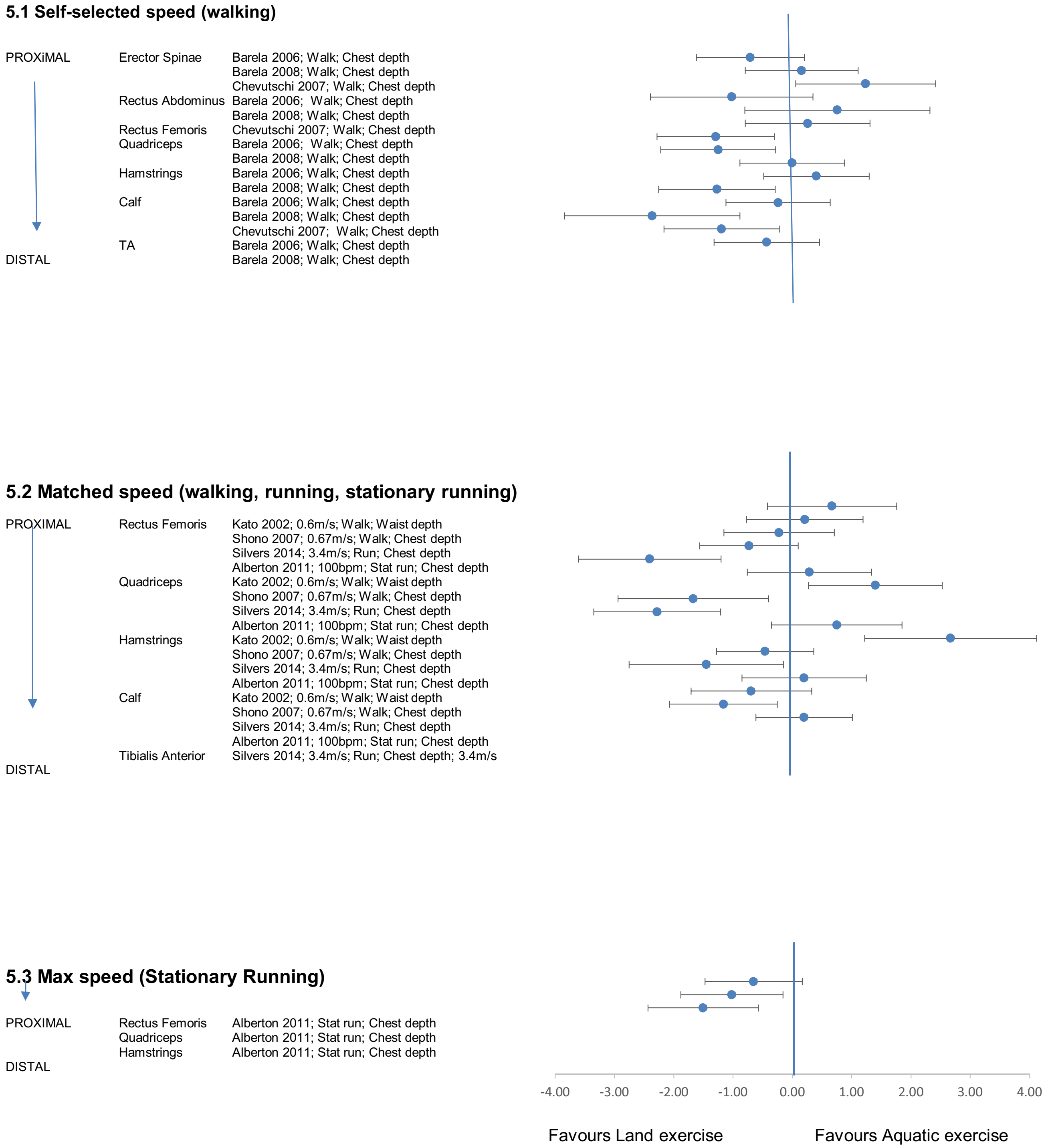

Fig. 5. (A) Average muscle activity. (B) Peak muscle activity.

advantages and limitations for aquatic exercise prescription, although there are still many gaps in the empirical knowledge base. Walking in water has similar kinematic outcomes at self-selected speed but is slower compared to on land. Due to slower self-selected and maximal speeds of movement in water for some functional tasks, active decisions about the instructions related to speed in aquatic therapy are required. Aquatic plyometric exercise offers similar loading in the propulsive phase while taking advantage of lower landing forces for joints. Gaps exist in understanding functional movement in water compared to on land as most of the research in this area relates to walking. Despite closed kinetic chain exercise being commonly prescribed in aquatic rehabilitation [53] there have been few studies examining these movements.

This review is the first to systematically identify that walking in water at self-selected speed is slower, results in similar lower limb joint range and muscle activity, and elicits lower vertical ground reaction force compared to walking on land. Overcoming drag forces is hypothesized to be the main factor leading to slower speeds of movement in water [13,26,39]. Despite these slower speeds of movement, the findings suggest there is value in walking in aquatic therapy programs through reproducing similar

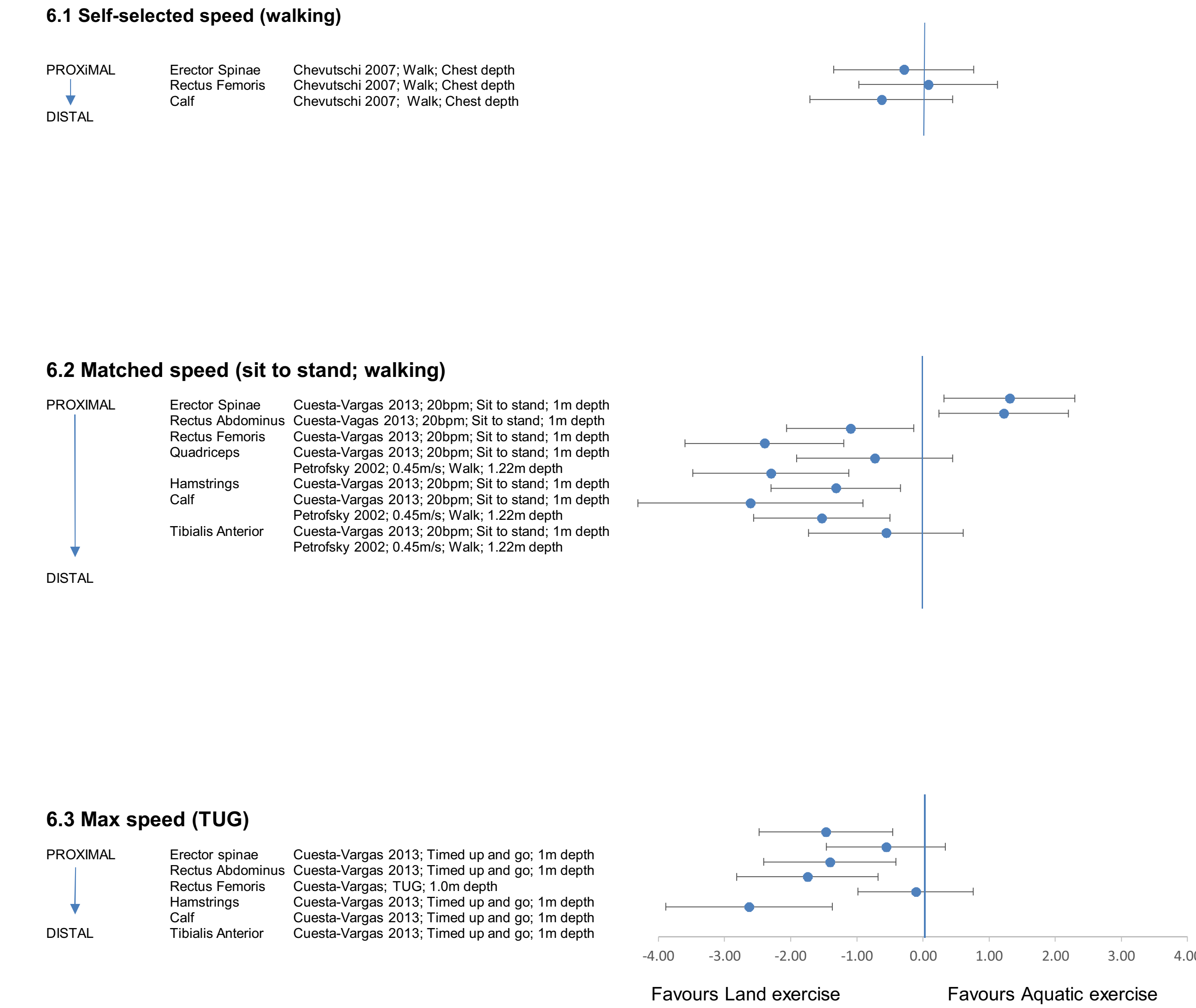

Fig. 6. Peak muscle activity.

movement strategies and subsequent joint range with lower compressive forces. This is an important consideration for people experiencing weight bearing restrictions, for example following orthopaedic surgery or a fracture [6] or with pain on loading as is common in hip and knee osteoarthritis [52].

The importance of instructions from the clinician related to speed with aquatic exercise is also highlighted in this review. Joint range is similar when walking at self-selected pace but the speed is slower in water compared to on land. In contrast, at matched speeds the pace is similar to land based walking but the joint range may be greater. Although only tested during walking, self-selected speed of other functional movement in water may also be slower. Clinicians can use instructions on speed as a tool to modify the biomechanical outcomes of the exercise in water for a particular outcome or to more closely match specific components of land-based activities of daily living. Alternately exercises may be performed at a range of speeds to address multiple outcomes. Improved understanding of movement in water compared to on land in addition to close observation of aquatic exercises will aid clinical reasoning, including decisions on instructions on speed, to increase benefit to the patient.

Maximal speeds of movement varied in water compared to on land depending on the exercise. The limitation in maximal speeds of some functional exercise in water parallels the finding of typically lower muscle activity at maximal speed. Once again, overcoming the drag from the trunk and legs moving horizontally with walking [31] or from the contralateral limb with stationary running [45] slows movement down in water [13,26,31,39,45]. This is a consideration when prescribing exercises as maximal speeds of functional movements may not be as fast in water as they are on land.

The propulsive phase of plyometric exercise is the exception to the trend of lower maximal speed exercise in water compared to on land. Similar maximal speeds between the two environments may relate to a number of factors; a smaller projected frontal area leading to lower drag forces or the ability of the leg extensor synergy to overcome the drag force. Similar maximal speeds of movement may facilitate the higher levels of VGRF in water compared to other functional exercises. The vertical direction of movement may also contribute stability to the exercise and therefore allow for potentially greater maximal speed. The downward force of gravity compared to movement in environments with reduced compressive forces has been hypothesized to add stability, reduce slippage, loss of balance and allow for more steady movement and greater speed of travel [54]. Similar speeds and forces in the propulsive phase may explain why aquatic plyometric training is as effective as land plyometric programs [55–57]. The added advantage of aquatic plyometric training in rehabilitation is the potential for reduced joint impact force on landing.

Variable study quality and heterogeneity across the methodology and activities did not allow completion of a meta-analysis and demands caution with generalizing the results. Statistically, the non-random, small subject numbers in the majority of the studies may lead to biased effect size estimates [58]. More information on average and peak muscle activity in different exercises and speeds is needed with consideration of the biomechanical and methodological constraints of studies using EMG. Not enough evidence exists currently to support the theory that there is higher average muscle activity in walking at self-selected speeds in water [13] or that distal leg muscle activation may be less than proximal leg muscle activation in water [12,39]. All studies included healthy participants, which is not necessarily generalizable to clinical populations, and therefore further research in these populations is required.

In conclusion, self-selected speed of movement is much slower in water, and therefore instructions on speed may be necessary in aquatic exercise to more closely approximate task specificity for improving land-based function. Maximal walking and stationary running leads to lower speeds in water compared to on land. In contrast, the propulsive phase of plyometric exercise is more similar between the two environments offering an opportunity for similar speed of movement and force. Value may exist in clinical scenarios to increase concentric loading while taking advantage of lower landing compressive forces for joints.

Conflicts of interest

None declared.

Appendix 1. Search strategy

PICO table.

Component of PICO question	Search terms
Population Humans/adults	Nil
Intervention Aquatic exercise or gait	Hydrotherapy, aquatic exercise*, water exercise*, aquatic therap*, aquatic rehab*, water aerobic*, aquarobic*, water walking, walking in water, shallow water, aquatic treadmill, underwater treadmill, aquatic environment, aquatic gait
Comparison Land based exercise or gait	Nil
Outcomes Electromyography, kinematics, kinetics, spatiotemporal parameters and forces	Biomechanic*, electromyography, kinematic*, kinetic*, acceleration, torque*, cadence, stride length, stance time, ground reaction force, rate of force development, neuromuscular, drag force*

Subject headings used across databases.

Database	MEDLINE complete (Ebsco) and The Cochrane Library		CINAHL complete (Ebsco)		SPORTDiscus (Ebsco)		Embase (OVID)	
MESH or subject heading or thesaurus	Hydro-therapy	Electromyography Kinetics Torque Biomechanical Phenomena (use for: Kinematics and Biomechanics) Acceleration Muscle contraction	Aquatic exercises Hydro-therapy	Biomechanics Electromyography Muscle contraction Neuromuscular control Kinematics Ground Reaction force Torque Kinetics Acceleration	Aquatic exercises Hydro-therapy	Electromyography Kinematics (includes motion, torque) Dynamics (use for kinetics) Acceleration (physiology) Acceleration (mechanics) Biomechanics	Aquatic exercise Hydro-therapy	Biomechanics Electromyography Muscle excitation Torque Acceleration Ground Reaction Force Kinematics Kinetics

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