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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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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

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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