Effect of water depth on muscle activity and stride duration when walking in the water at different speeds

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Abstract

Aquatic exercise is popular for training and rehabilitation, but information on how the water depth affects muscle activity when walking is lacking. The purpose of this study was to compare muscle activity when walking on land and at knee, pelvis and xiphoid process depth in a swimming pool. Twelve participants (22±3.6 years; 70.9±14.5kg; 1.7±0.1m) walked on land and on the pool floor at each of the three depths, at a self-selected (V_{self}) and a maximum speed (V_{max}). Mean and peak muscle activity was recorded for the rectus femoris (RF), biceps femoris (BF), medial gastrocnemius (GM), lateral gastrocnemius (GL), tibialis anterior (TA) and erector spinae (ES). Stride duration was also recorded. Stride duration decreased and activity of all muscles increased from V_{self} to V_{max}, except peak values at xiphoid process depth. For the depth comparisons, most changes in muscle activity occurred in the RF and BF, with higher values generally occurring at knee and pelvis depth, and stride duration continually increased with depth. These findings provide useful information on the musculoskeletal demands of walking in the water that can be used to inform design and prescription of exercise programmes for rehabilitation.

Keywords; Aquatic, Land, Exercise, Electromyography, Rehabilitation

Introduction

Aquatic exercise is popular for rehabilitation of athletes and patients (Stevens, Caputo, Fuller & Morgan, 2015; Heywood, McClelland, Geigle, Rahmann & Clark, 2016). This is largely because aquatic exercise has some important benefits compared to exercise on land, such as: the warm water can facilitate muscle relaxation; hydrostatic pressure provide support, because fluid pressure is exerted equally on all surfaces of an immersed body and is proportional to water depth; water resistance may challenge movement more than air on land; buoyancy reduces spine and joint loading; exercising in the water may reduce pain intensity and frequency during musculoskeletal disorders such as back pain (Harrison, Hillman & Bulstrode, 1992; Carneiro et al., 2012; Cuesta-Vargas & Cano-Herrera, 2014; Psycharakis, Coleman, Linton, Kaliarntas & Valentin, 2019). Implementing electromyography (EMG) during aquatic activities such as walking can aid development, prescription and progression of exercise for health and rehabilitation (Chevutschi, Lensel, Vaast & Thevenon, 2007; Masumoto, Takasugi, Hotta, Fujishima & Iwamoto, 2007; Psycharakis et al., 2019). Combined with temporal gait kinematical analysis, it may facilitate development of rehabilitation programmes where simultaneous muscular training and re-learning of gait patterns are desirable; for example, in orthopaedic patients following long-term immobilisation. Several studies have therefore compared EMG activity and temporal gait kinematics between walking in water and on land.

EMG studies in this area focused primarily on the rectus femoris (RF), biceps femoris (BF), medial gastrocnemius (GM), lateral gastrocnemius (GL), tibialis anterior (TA) and erector spinae (ES). They typically reported lower activity in water compared to on land, with aquatic EMG values ranging from 3-20% maximum voluntary contraction (MVC) (Kaneda et al., 2004; Masumoto et al., 2004; Masumoto, et al., 2005; Barela et al., 2006; Chevutschi et al., 2007; Shono et al., 2007; Kaneda et al., 2007; Masumoto et al., 2008). These studies displayed useful findings but also there were also some differences in their results. For example, walking in water at half the speed of that on land lowered BF and TA activity in some studies (Masumoto et al., 2008), but not in others (Shono et al., 2007). Similarly, when walking speed for the two environments was matched the effects on activity of the BF and TA were often inconsistent between studies (Masumoto et al., 2008; Shono et al., 2007; Kaneda et al., 2007). Some of these contradictions possibly resulted from methodological differences, such as in participant characteristics (e.g. young vs elderly), speeds used during trials or variations in the guidelines used for electrode placement (unmentioned in most studies). Thus, more data are needed to improve our understanding on the demands of walking in water compared to land.

As some rehabilitation facilities have swimming pools allowing depth adjustments, walking in water may take place at different depths. This is important as immersion depth, and therefore volume of water displaced, directly influences buoyancy, hydrostatic pressure and resistance, largely determining exercise demands (Torres-Ronda & Schelling i del Alcázar, 2014). Considering no studies have explored the differences in EMG activity when walking at different immersion depths, this area warrants further investigation. Temporal gait kinematic analyses seem to suggest cadence decreases with immersion depth (Kato, Onishi and Kitagawa, 2001; Pohl & Mcnaughton, 2003; Jung et al., 2018), however all differed in methods and depths assessed (pelvis, waist or chest depth), limiting generalisability of findings. Although Fantozzi, Giovanardi, Borra and Gatta (2015) reported stride duration to be higher in water than on land, they used just a single depth (1.2m). Finally, no studies have assessed EMG at knee depth so research into this condition would be useful.

In addition to the above, there are some further limitations and gaps in existing research. One such limitation relates to achieving similar effort between the conditions of walking in the water and on land. Several studies set aquatic speed to half of that on land to account for water resistance, but it is uncertain if this accurately represents the difference between environments in the effort required to walk. Matching walking speed between environments, would likely also cause greater effort in the water, due to the increased resistance to movement. Using a self-selected speed (a specific effort level) or a maximal walking speed could theoretically make the replication of effort in the two environments more likely. Although some studies used the former method, instructions on how to self-select speeds were absent, so overall effort levels may still have been different. No studies have explored maximal walking speeds in the water and on land (Torres-Ronda & Schelling i del Alcázar, 2014). Moreover, in many studies, water treadmills were used and participants walked against a water current. This has been reported to alter walking mechanics (Nymark, Balmer, Melis, Lemaire & Millar, 2005), possibly affecting EMG activity and temporal kinematics, and water treadmills may be unavailable in many pools, limiting applicability of many findings to the general population. Exploring the effects of immersion depth and speed on gait when walking on the pool floor would be beneficial. Finally, peak EMG activity has only been reported in one study and just qualitatively (Barela et al., 2006). However, considering that muscle activity during a gait cycle would often fluctuate, peak EMG data could provide useful information on the levels of the highest activity reached during the gait cycle, which may otherwise be masked within the mean data and lead to incorrect assumptions on the highest levels of activity that may be reached for certain muscles during periods of the gait cycle. Quantitative comparison of peak EMG activity between walking in water and on land is therefore needed to provide health professionals with more important information that would help develop rehabilitation programmes.

In view of the above, the aim of the present study was to compare muscle activity when walking on land and at knee, pelvis and xiphoid process (Xp) depth in a swimming pool, at a self-selected (V_{self}) and maximum speed (V_{max}). We focused on both the mean and peak muscle activity, as well as on stride duration. We hypothesised muscle activity awould be higher and stride duration lower at V_{max} than V_{self}. Since resistance increases with surface area, we hypothesised increasing depth would produce greater activity of muscles required for horizontal propulsion, such as the BF and gastrocnemius (Dahmane, Djordjevič & Smerdu, 2006; Hamner, Seth & Delp, 2010), while RF, TA and ES activity would decrease due to buoyancy. Finally, we hypothesised stride duration would increase with depth. (Jung et al., 2018).

Methods

Participants

A Power calculation using GPower (version 3.1.9.4) indicated a sample size of 12 would provide 89% power in identifying a large effect size (partial Eta squared of 0.1379) (Richardson, 2011; Psycharakis et al., 2019) at the 0.05 level (with the default assumption of 0.5 correlation among repeated measures). Twelve healthy participants, six females and six males (22±3.6 years, 70.9±14.5kg, 1.7±0.1m) volunteered to participate in this study. Participants were recreationally active and had no injuries or illness. The study was approved by the School's ethics committee and all participants provided written informed consent before the study commenced.

Procedures

Data collection took place in an indoor swimming pool with a manually movable floor, adjustable to each participant's knee, pelvis and xiphod process (Xp) depth. Water temperature was maintained between 26.5-28.0°C (Masumoto et al., 2004) and participants wore their typical swim wear, i.e. swimming suits or shorts. Following electrode attachment, participants completed MVC exercises for the muscles analysed, adhering to Konrad's (2006) guidelines; a three-second, dynamic contraction, followed by a three-second maximal isometric contraction, repeated twice. Table 1 provides information regarding MVC exercises. Familiarisation trials, conducted on land and each depth, lasted three minutes, characterised as sufficient in previous aquatic exercise research (Mills, Ayres & Scurr, 2015). Participants continually walked back and forth on land and on the pool floor, at two speeds. At V_{self}, participants were asked to walk at a speed that did not induce any discomfort and was sustainable for at least one hour. At Vmax, participants were asked to walk at the highest speed they could achieve without running (ie. no instances where both feet were simultaneously not in contact with the pool floor). While arm movement was not restricted, participants could not use their arms for propulsion. Each participant performed one two-minute trial at each speed and depth. For practical and technical reasons concerning operation of the pool floor, land trials were performed first, then aquatic trials followed in order of depth. V_{self} was the first walking speed conducted, followed by V_{max}, after which a 3-minute rest was given, allowing full recovery (Masumoto et al., 2008). Considering the V_{self} pace description and the duration of these trials, the V_{self} pace was not expected to induce any fatigue or discomfort. Therefore, the rest between a V_{self} and V_{max} trial was minimal (e.g. under 30s). Additionally, participants were told that they could have longer rest between subsequent trials, should they wish so or feel fatigue/discomfort. No participants opted for longer rest during testing.

Insert Table 1 around here

EMG signals were recorded at 2000Hz from the right RF, BF, TA, GM, GL and ES. Electrodes were wireless, waterproof, pre-gelled (Cometa SRL, Milan, Italy) and positioned 20mm apart parallel to the muscle fibres, following SENIAM's guidelines for electrode location (2018). Skin was shaven, minimising inter-electrode resistance (Masumoto et al., 2008). A transparent waterproof film was used to further minimise risk of water permeation between the skin and electrodes and electrodes were secured using a highly adhesive, waterproof tape (not inhibiting normal bodily movement), minimising movement artefact (Masumoto et al., 2008). To screen for events that could have contaminated the analysis, such as participants losing their footing, video data were captured from a side view at 240Hz using a GoPro (HERO4 Silver, GoPro, USA), attached to a metal rod, by a researcher that walked alongside participants for each trial.

Data analysis and reduction

EMG recordings were processed on EMG Motion and Tools Version 5.3.4.0 (Cometa, Italy). Signals were rectified and pass-band filtered using a second order Butterworth filter with 20 and 500Hz cut-off frequencies (Chevutschi et al., 2007; Masumoto et al., 2008). Five full, stable gait cycles, determined by EMG events, at the beginning of each trial were selected for analysis (Masumoto et al., 2004; 2007; 2008). EMG data were analysed on Microsoft Excel for Office 365 (Microsoft, UK). Mean EMG was determined by averaging EMG activity over the five gait cycles. Peak EMG was calculated as an average of the five peak readings for each gait cycle. Because peak EMG values during maximal speed trials often exceeded those recorded during the MVC trials, EMG data were normalised to the highest recorded value during trials (Assaiante, Woollacott & Amblard, 2000; Casartelli et al., 2011; Halaki & Ginn, 2012). Stride duration was calculated by dividing the time taken to complete the five gait cycles by five.

Statistical analysis

Statistical analyses were conducted on IBM SPSS Statistics (Version 26, IBM SPSS Software, USA). Descriptive statistics included mean and standard deviation and normality was assessed using the Shapiro-Wilk statistic. Main effects for speed, depth and the speed-depth interaction for normal data were yielded by two-way, repeated measures analysis of variance (ANOVA), with depth the repeated measure, and reported using partial Eta squared (η^2). Small, medium, and large effects were classified as values of 0.0099, 0.0588, and 0.1379, as described by Richardson (2011) and in line with other studies on aquatic exercise in shallow water (Psycharakis et al. 2019). The Greenhouse-Geisser correction was performed when Mauchly's test indicated violated sphericity. Mean and peak RF, BF, GM and mean GL data violated normality so were analysed non-parametrically using Wilcoxon's signed-rank test for speed and a Friedman's test for depth. Although Friedman's test does not allow for assessment of interaction effects, the speed-depth interaction was determined by performing Friedman's tests on the difference scores between V_{max} and V_{self} trials at each depth. Significance was accepted for $p \leq 0.05$.

To determine the effect of velocity in each of the four walking conditions, paired samples t-tests and Wilcoxon signed-rank tests were performed on normal and non-normal data, respectively, for each condition, with significance accepted for $p \leq 0.05$ level. Pairwise comparisons were conducted, using paired-samples t-tests for normal data and Wilcoxon signed-rank tests for non-normal data, to determine where depth effects elicited at V_{self} and V_{max}. To eliminate the possibility of type I errors in these tests, we divided the alpha level with the number of pairwise comparisons (six) and accepted significance for $p \leq 0.0083$ (Field, 2009). Stride duration was analysed parametrically, mirroring EMG statistical analyses. Effect sizes for differences between depths and between walking speeds at each depth were reported using Cohen's (d) statistic and characterised as small (0.2), medium (0.5) and large (0.8) (Cohen, 1988).

Results

Table 2 displays main effects for speed, depth and the speed-depth interaction, with mean and peak EMG and pairwise comparisons for depth in Figure 1. All muscles showed a significant effect for speed. On land and at knee and pelvis depth, V_{max} required significantly greater mean and peak muscle activity than V_{self} for all muscles ($<0.001 \leq p \leq 0.034$; $0.60 \leq d \leq 2.90$). At Xp depth, mean EMG was significantly greater at V_{max} than V_{self}, although effect sizes were lower ($0.003 \leq p \leq 0.05$; $0.34 \leq d \leq 0.72$). Peak EMG was not statistically different between V_{self} and V_{max} at Xp depth ($0.071 \leq p \leq 0.480$; $0.22 \leq d \leq 0.92$), except for the BF ($p=0.002$; $d=0.78$). The depth main effect was significant for all muscles for mean EMG activity, and for the RF, GM and BF for peak EMG activity, although the GM did not display any significant pairwise comparisons. Highest values occurred mostly at either knee or pelvis depth. The speed-depth interaction was significant for mean and peak RF, mean TA and ES and peak BF activity.

Insert Table 2 around here

Insert Figure 1 around here

EMG Pairwise Comparisons

All significant pairwise comparisons for mean EMG had large effect sizes, except land Vs knee activity for the BF (d=0.62).

At V_{self}, mean RF activity was significantly greater at knee depth than on land and Xp depth, and at pelvis than Xp depth. The greater mean activity at pelvis depth than on land produced a large, non-significant effect size (p=0.026; d=1.05). At V_{max}, mean RF activity was significantly greater at knee depth than any other condition, and at pelvis than Xp depth. Peak muscle activity at V_{self} for the RF was significantly greater at knee and pelvis depth than on land and Xp depth. At V_{max}, peak RF activity was significantly greater at knee depth than any other condition, and at pelvis than Xp depth. The former demonstrates the interaction between speed and depth since knee Vs pelvis comparisons were not significant for peak RF activity at V_{self}. The greater peak RF activity at pelvis depth than on land at V_{max} produced a large, non-significant effect size (p=0.023; d-=1.27).

At V_{self}, mean BF activity was significantly greater in all aquatic conditions than on land. At V_{max}, mean BF activity was significantly greater at knee and pelvis depth than on land. An interaction between speed and depth was present for BF mean EMG since land Vs Xp comparisons did not reach significance at V_{max}. Peak muscle activity at V_{self} for the BF at was significantly greater at knee and pelvis depth than on land and, while not statistically significant, produced a large effect size for the greater peak activity at Xp depth than on land (p=0.012; d=1.01). Similarly, for the BF, the greater peak activity at knee (p=0.01; d=1.57) and pelvis (p=0.028; d=1.69) depth than on land at V_{max} did not reach significance, demonstrating an interaction between speed and depth, but produced large effect sizes.

At V_{self}, mean GL activity was significantly greater at knee depth than on land, and at pelvis than Xp depth when at V_{max}. Mean TA activity at V_{max} was significantly greater at knee than Xp depth. No pairwise comparisons for low leg peak EMG reached significance at either speed.

At V_{self} and V_{max}, mean ES activity was significantly greater at pelvis than knee depth and the greater activity at Xp than knee depth produced a large, non-significant effect size both speeds (V_{self}, p=0.026; d=1.22: V_{max}, p=0.038; d=1.02). Similarly, the greater mean ES activity at pelvis depth than on land produced a large effect size at both speeds (V_{self}, p=0.020; d=1.00: V_{max}, p=0.025; d=1.08).

Stride duration

Table 3 displays stride duration results. Significant effects for speed, depth and the interaction were present. Stride duration was significantly greater at V_{self} than V_{max} in all conditions ($0.001 \leq p \leq 0.004$; $0.89 \leq d \leq 3.07$). At V_{self} and V_{max}, stride duration showed a continual significant increment with depth.

Insert Table 3 around here

Discussion

This study sought to assess how changes in depth influence low-limb muscle activity when walking at V_{self} and V_{max}, and how muscle activity and stride duration compare with walking on land. This is the first EMG study to include three different immersion depths that are commonly used in training and rehabilitation, and therefore provides novel data that could be used to improve quality and effectiveness of programme prescription for rehabilitation.

Muscle activity

In all cases excluding peak values at Xp depth, V_{max} required greater mean and peak activity of all muscles, consistent with previous research where muscle activity was compared when walking in water and on land at slow, moderate and fast speeds (Shono et al., 2007). Moreover, V_{max} trials generally induced EMG activity increments of at least 30%, with increments in the larger muscles sometimes approximating 100%. Such information on the magnitude of increase in muscle activity may be particularly useful when devising rehabilitation or exercise programmes.

When considering the differences between land and the three immersion depths, the highest values for muscle activity mostly occurred at knee or pelvis depth. Most significant differences were observed for the RF and BF, but significant differences were also recorded for all other muscles for mean EMG except the GM. Large effect sizes were observed for some comparisons that, while not statistically significant, aligned with trends shown by the statistically significant comparisons. Considering the sample size of the present study, it was deemed appropriate to discuss further comparisons that were not statistically significant but had large effect sizes.

The RF showed the highest number of significant differences between conditions. Walking at knee depth seemed to produce higher RF activity than on land and other immersion depth in most cases, while walking at pelvis depth also had higher activity than at Xp depth and, often, than on land. Despite approximately 70% of vertical weight bearing being unloaded (Harrison et al., 1992), RF activity was not significantly different at Xp depth compared to land. This is possibly because reductions in RF activity associated with weight bearing may have been negated by the greater work required to overcome water resistance when moving forward, since participants in the present study walked on the pool floor rather than a treadmill. Although contradicting preceding research (Chevutschi et al., 2007; Kaneda et al., 2007), this finding likely explains why RF activity increased from land to pelvis and knee depth. The increase in RF activity from land to knee depth likely occurred because, at knee depth, the RF simultaneously flexes the hip, without aid from buoyancy, and extends the knee against water resistance incurred on the shank. At pelvis depth the thigh is entirely submerged so buoyancy, additionally acting more on the lower leg (Torres-Ronda & Schelling i del Alcázar, 2014), aids hip flexion. This might partially explain the subsequent significant decrease in RF activity from knee to pelvis depth at V_{max} and to Xp depth at both speeds. Also, actual walking speeds were reducing with immersion depth, because water resistance was greater, further facilitating the decrease in RF activity with depth.

For the BF, walking at pelvis depth produced the highest activity, with pelvis and knee values being generally higher than those on land. As the BF is important for horizontal propulsion (Dahmane et al., 2006), increased BF activity in the water compared to land, where resistance to movement is minimal, was anticipated. Bearing this in mind, it is interesting that V_{max} trials did not elicit greater activation of the BF at Xp depth than on land, although a similar result was observed by Masumoto et al. (2008). The greater BF activity at knee depth is also interesting, perhaps attributable to an increase in knee flexion during the swing phase in attempt to ‘clear’ the water before the foot re-entered and may explain the moderate effect size produced for V_{self} land-knee comparisons. After foot re-entry, the RF would become responsible for extending the knee against water resistance incurred on the shank of the leading leg. BF activity did not seem to vary significantly with immersion depth, despite a slight trend for higher values at pelvis depth. BF fibre recruitment with changing depth may be affected by several factors, such as overall walking speed, lower limb segment speeds and other relative low-limb muscle contribution to movement, which may further contribute to the variability in peak EMG values.

In the lower leg, only three pairwise comparisons across all conditions reached significance. GL mean activity at V_{self} was higher at knee depth compared to on land, possibly because weight is not unloaded considerably at knee depth. The lack of significant differences in GL and GM activity at pelvis and Xp depth, compared to that on land, may reflect the likely absence of 'heel strike' at greater depths, due to increased torso horizontality, counteracting the reduction in horizontal weight bearing. Lower mean GL activity at pelvis than Xp depth at V_{max} may result from reduced vertical weight bearing, although, given that the GM did not show this trend, it may be more likely that it reflects changes in tibial rotation and foot position in response to greater instability when walking at greater depths. This is plausible considering low leg EMG was generally variable, signified by the low peak EMG values at V_{max}. No other significant differences emerged for low leg EMG, except lower mean TA activity at knee than Xp depth at V_{max}, nor any clear trends. This may be because low-leg EMG can be influenced by other factors such as ground reaction force-induced soft tissue vibrations (Wakeling, Von Tscharner, Nigg & Stergiou, 2001; Boyer & Nigg, 2004).

At both V_{self} and V_{max}, mean ES activity was significantly higher at pelvis than knee depth and showed large, albeit non-significant, effect sizes for higher activity at pelvis depth than on land and Xp than knee depth. A larger sample may have yielded statistical significance for the latter comparisons. The generally higher activity at pelvis and Xp depth likely results from increased torso horizontality. Despite greater torso horizontality at Xp than pelvis depth, more buoyancy is exerted on the torso at Xp depth, thus mean activity was not significantly different between these conditions. Further, during V_{max} trials, mean ES activity in fact decreased beyond pelvis depth. This is probably due to increased water resistance at Xp depth bearing most of the torso's weight and unloading the ES, considering the relationship between movement speed and water resistance (Torres-Ronda & Schelling i del Alcázar, 2014). Given that peak ES activity did not show an effect for depth, this may suggest the duration rather than magnitude of contraction is impacted by depth and environment changes. Finally, although mean EMG values for most muscles in the present study may seem low compared to those in some previous studies, this could be mainly attributed to methodological differences in EMG processing, as many previous studies normalised EMG by using an average value over time, rather than a single maximum value.

Stride duration

As hypothesised, stride duration was greater in water, and increased with immersion depth at both walking speeds, supporting prior research where cadence decreased with increasing depth (Pohl & Mcnaughton, 2003; Jung et al., 2018). This reflects the increased challenge and resistance to walking in water with increasing depth, causing slowing of movement. Clinically, this is useful for gait rehabilitation following long-term injury- or disease-induced immobilisation. Namely, the lengthened duration of each stride allows directing of focus towards elements of gait possibly impaired following immobilisation, such as normal foot pronation as weight shifts from the rear to the forefoot.

Limitations and future directions

There are some limitations in the present study. First, the intensity and perceived effort were not measured and, although this is also normally the case in rehabilitation sessions, they could have been subject to variation. Second, the lack of trial randomisation with respect to speed and depth may cause fatigue and learning effects. Nevertheless, to minimise any such effects, all participants were provided with substantial time to practise all conditions, and sufficient rest was provided between trials to avoid fatigue. Third, the trials often produced higher EMG values than the MVC exercises. Although data normalisation was performed through the highest value obtained in the trials, it is recommended that future studies explore different and/or multiple types of MVC exercises. It is also noted that different normalisation methods have been used in the literature, which should be taken into account when comparing the results of different studies. Finally, the present study chose to analyse EMG for the whole gait cycle, given that in the vast majority of cases a full walk is prescribed in rehabilitation. Nevertheless, breaking down the gait cycle into different phases, such as swing and stance, and performing a temporal analysis of EMG, could improve our knowledge of muscle activity changes throughout the course of a gait cycle.

To improve further our understanding of how exercise is affected by the aquatic environment, is recommended that additional variables are explored, such as angular velocity and displacement of lower extremity joints, and that other muscles possibly contributing to walking are included, such as the rectus abdominis, and gluteus maximus. Any effects of fatigue on muscle activity could also be investigated in future research, where EMG is assessed in longer trials over time. It is also recommended that future studies gauge EMG when walking on land and at different depths at V_{self} and V_{max} in different subphases gait.

Practical applications

This is the first study on the influence of depth changes on activity of low-limb muscles when walking at V_{self} and V_{max}. It therefore provides useful information that can inform exercise recommendations for rehabilitation or training of specific muscles. Muscle activity levels when walking at various immersion depths appear either similar or higher than those on land. This has implications for individuals who require management of loading on joints and skeletal structures, while simultaneously strengthening the muscles. Many individuals cannot perform land-based exercise due to issues with balance and greater risk of falls, therefore walking in water provides a safe alternative. When comparing immersion depths, highest RF activity generally seems to occur when walking at knee depth, and BF activity at pelvis depth. Walking at Xp depth did not seem to produce additional muscle activity for any of the muscle analysed, compared to knee and pelvis depth. The relationship between ES activity and depth is important considering severity of spinal injuries and the need for careful rehabilitation in such cases.

Conclusion

The present study sought to evaluate how muscle activity and stride duration were affected by changes in walking speed and water depth when walking on land and at knee, pelvis and Xp water depth. Most changes in muscle activity occurred in the RF and BF, with higher values occurring primarily at knee and pelvis depth. EMG activity of lower leg muscles was often variable and did not appear to be affected substantially by depth, with only rare cases of significant differences. Pelvis depth elicited the highest ES activity. All muscles showed an increase in activity from V_{self} to V_{max}, except for peak activity at Xp depth. Stride duration decreased from V_{self} to V_{max} at all depths and continually increased with depth. These findings provide useful information on the musculoskeletal demands of walking in the water that can be referred to in the creation and prescription of exercise programmes for rehabilitation.

Disclosure of interest

The authors report no conflict of interest.

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Table 1. Description of exercises and positions used for measurement of maximal voluntary contractions.

Muscle	Position	Description
RF	Sitting	Exercise 1– participant sits on chair with thigh supported with 90 degrees hip and knee flexion and tries to extend knee. Exercise 2 – Participant sits as above except knee is in an extended position and participant attempts to resist knee flexion.
TA	Standing	Participant stands and attempts to dorsiflex the ankle against resistance.
GM	Standing	Participant stands and attempts to plantar flex against resistance.
GL	Standing	Participant stands and attempts to plantar flex against resistance.
BF	Prone lying or standing	Exercise 1– participant lies prone with neutral hip and knee and attempts to flex knee against resistance. Exercise 2 – participant lies as above except knee is in 90 degrees flexion and participant attempts to resist knee extension.
ES	Prone lying	Participant lies prone and extends the spine as far as possible.

Table 2. Main effects for speed, depth and the interaction on mean and peak muscle activity.

Muscle	Main effect					
	Speed		Depth		Interaction	
Mean	(p)	η^2	(p)	η^2	(p)	η^2
RF	**0.002**	n/a	**<0.001**	n/a	**<0.001**	n/a
TA	**<0.001**	0.802	**0.011**	0.308	**0.011**	0.307
GM	**0.002**	n/a	**0.006**	n/a	0.271	n/a
GL	**0.002**	n/a	**0.023**	n/a	0.096	n/a
BF	**0.003**	n/a	**0.005**	n/a	0.074	n/a
ES	**<0.001**	0.808	**0.017**	0.387	**0.043**	0.256
Peak						
RF	**0.002**	n/a	**<0.001**	n/a	**0.006**	n/a
TA	**<0.001**	0.866	0.147	0.161	0.072	0.205
GM	**0.003**	n/a	**<0.001**	n/a	0.212	n/a
GL	**<0.001**	0.801	0.126	0.157	0.169	0.140
BF	**0.003**	n/a	**0.002**	n/a	**0.016**	n/a
ES	**<0.001**	0.908	0.171	0.181	0.152	0.175

Bold indicates significance ($p<0.05$)
n/a: This indicates the use of non-parametric analysis of variance (Friedman's test), which does not allow calculation of eta squared. Effect sizes for those tests have been performed for the post-hoc comparisons.

Table 3. Stride duration on land and at knee, pelvis and xiphoid process (Xp) depth at V_{self} and V_{max}. Main effects for speed, depth and the interaction.

Speed	Stride duration (seconds)				Main effects					
	Land	Knee	Pelvis	Xp	Depth		Speed		Interaction	
Self					(p)	η^2	(p)	η^2	(p)	η^2
Mean	1.09	1.37	1.65	2.02	<0.001	0.774	<0.001	0.780	0.104	0.168
SD	0.07	0.15	0.21	0.55						
Max										
Mean	0.89	1.10	1.34	1.61						
SD	0.06	0.12	0.23	0.35						

For all pairwise comparisons $<0.001 \leq p \leq 0.008$; $0.89 \leq d \leq 3.58$

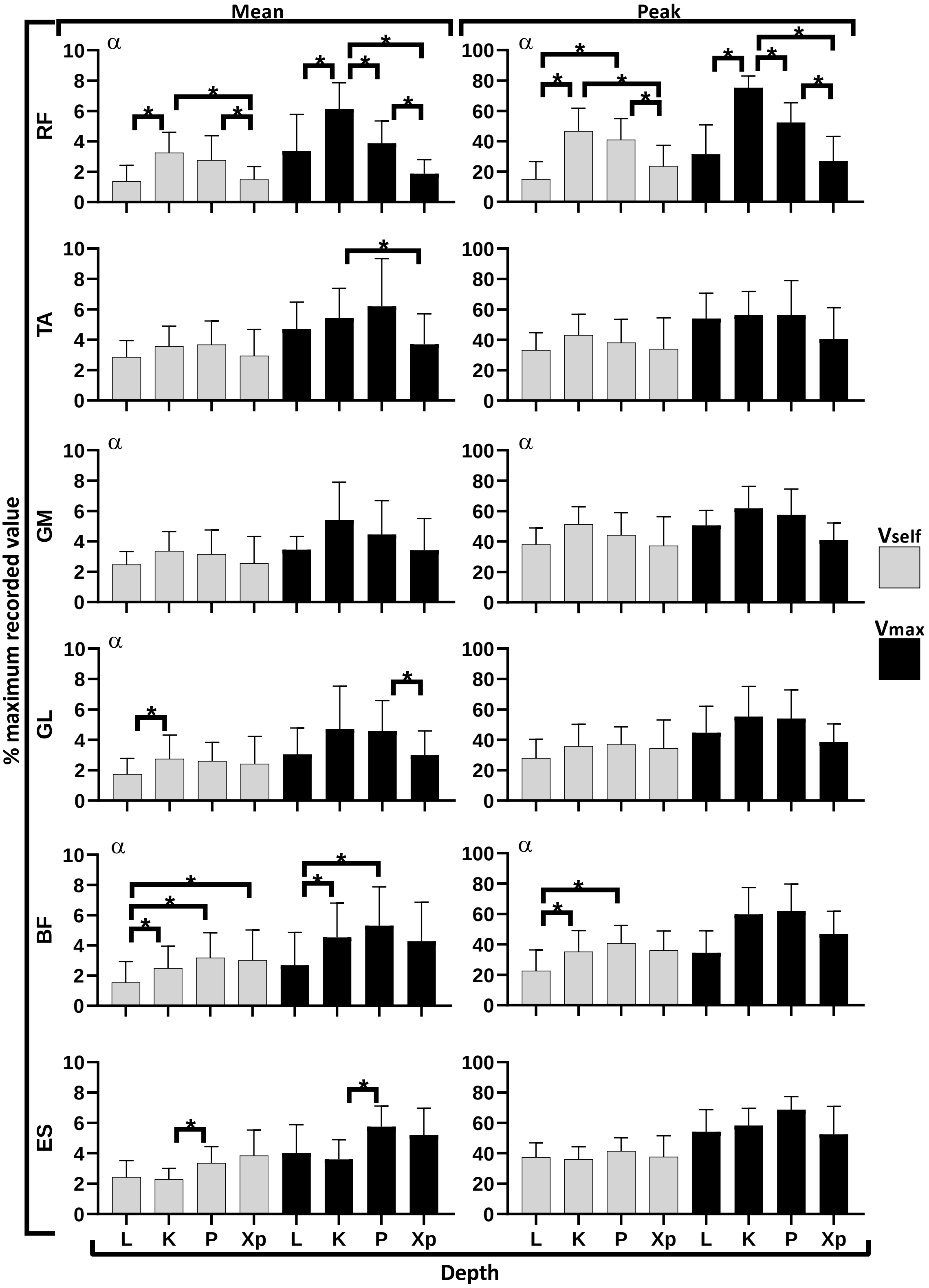

Figure 1. Mean and peak EMG activity of the rectus femoris (RF), tibialis anterior (TA), gastrocnemius medialis (GM), gastrocnemius lateralis (GL), biceps femoris (BF) and erector spinae (ES) at V_{self} and V_{max} at land (L), knee (K), pelvis (P) and xiphoid process (Xp) depth.

α: Non-parametric pairwise comparisons

*: $p<0.0083$; $d\geq0.8$; $r\geq0.5$