

Title: Muscle Activity During Aquatic and Land Exercises in People With and Without Low Back Pain

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Background. Chronic low back pain (CLBP) is the most prevalent musculoskeletal disorder. Aquatic exercises are commonly used by physical therapists for CLBP treatment and management; however, there are no data on trunk muscle activation during aquatic exercises in people with CLBP.

Objective. We quantified activation of trunk and gluteal muscles, exercise intensity, pain, and perceived exertion in people with and without CLBP when performing water and land exercises.

Design. The study used a cross-sectional design.

Methods. Twenty participants with non-specific CLBP and 20 healthy participants performed 15 aquatic exercises and 15 similar land exercises. Mean and peak muscle activation were measured bilaterally from erector spinae, multifidus, gluteus maximus, gluteus medius, rectus abdominis, external oblique, and internal oblique, using waterproof and wireless surface electromyography. Exercise intensity (heart rate), perceived exertion (Borg scale), and for the CLBP group, pain (visual analog scale) were recorded.

Results. There were no significant between-group differences. Significant between-environment differences were found in heart rate (always higher on land), exertion (higher in the water for 3 exercises and on land for 6 exercises) and muscle activation (higher on land in 29% and in the water in 5% of comparisons). Pain levels were low, but pain was reported more than twice as frequently on land than in water (7.7% vs 3.7%, respectively).

Limitations. People with high levels of disability and CLBP classification were not included.

Conclusions. People with mild-to-moderate CLBP had similar exercise responses to healthy controls. Aquatic exercise produced sufficient muscle activation, intensity, and exertion, and should not be assumed to be less strenuous or less effective in activating trunk and pelvic muscles than exercise on land. These data can be used to inform design and prescription of rehabilitation programs and interventions.

Low back pain (LBP) is the most prevalent musculoskeletal disorder (MSD), affecting nearly everyone at some point during their lifetime and between 4% to 33% of the population at any given time.^{1,2} LBP has a major impact on quality of life and is also a cause of disability and absence from work. For example, circa 150 million working days are lost annually in the USA because of back pain³, while in the UK over 200,000 people report back pain at work at least once every year.⁴ LBP has also a very high economic cost, with the annual cost in the USA, for instance, estimated at \$100-\$200 billion.⁵ The majority (85%) of LBP cases are described as ‘non-specific’ due to a mismatch between symptoms and radiological findings.⁶ Recurrence and chronicity are common, with less than 40% of patients being pain-free 12 months after an acute LBP episode.⁷

Exercise therapy on land targeting spinal and trunk musculature commonly forms the foundation of clinical programs for people with chronic LBP (CLBP) and has been shown to reduce pain and disability and improve muscle function and strength.^{8,9} Approaches in exercise programmes include generalised graded exercise and exercises which target the recruitment of specific muscles to improve lumbopelvic stability, as altered neuromotor control of the spine and pelvis¹⁰ and generalised weakness around the hip and abdominal muscles have been identified in this population.¹¹ Aquatic exercise is also often used in the management and treatment of LBP, as it has some important benefits compared to land exercise and may assist with balance, mobility and pain control. For example, warm water can facilitate muscle relaxation¹², buoyancy reduces joint loads¹¹ and hydrostatic pressure provides support¹. Studies on aquatic exercise have reported positive effects on patient outcomes, such as improved function and muscular endurance, increased spinal flexibility and reduced absence from work.¹³⁻¹⁸

With the positive effects of exercise well documented¹⁹, leading bodies such as the UK's National Institute of Health and Care Excellence recommend exercise in all its forms for people with LBP.²⁰ However, it is not yet known which form of exercise may be superior for the management or treatment of LBP.²¹ Aquatic exercise has been reported to have similar^{14,18} or greater improvements^{1,13,16,17} than land programmes and may be more appropriate for people with LBP, in particular for initial stages of rehabilitation and for those who have difficulties performing land exercises.²²

Nevertheless, despite the evidence on aquatic exercise usefulness for people with LBP, practical application of research findings in this area is still limited. One reason is that the programmes and exercises used in aquatic studies are typically not well reported or even completely absent.¹ Moreover, to maximise programme effectiveness and specificity, it is vital that exercises target directly the muscles of interest. However, due to the complexities of electromyography (EMG) measurements in the water, knowledge of trunk muscle activation during aquatic rehabilitation exercises is very limited. The most commonly tested exercises are underwater walking or deep water running^{23,24}, with just a few studies investigating a small number of rehabilitation exercises.^{22,25} Furthermore, EMG studies have typically used electrodes on one side of the body directly linked by cables to external receivers. Such systems cause active drag, affect exercise execution and inhibit movement disproportionately between left and right. They also provide only unilateral information on muscle activity, a potentially important limitation, particularly for asymmetrical exercises.²⁶ Finally, no aquatic studies have measured trunk muscle activity in people with CLBP. With studies on land reporting mal-adaptations of the neuromuscular system of the spine for people with CLBP²⁷ and also differences in muscle activation between people with and without CLBP¹⁰, EMG data during aquatic exercises are required for people with CLBP.

Considering the above limitations, exercise selection by physiotherapists is often arbitrary or based on anecdotal evidence. Further research in this area with improved methods is therefore needed to advance knowledge and facilitate generalisability of findings. This would provide an evidence base to inform clinical practice and exercise prescription, which could then lead to improved quality, efficiency and effectiveness of exercise interventions and rehabilitation. Thus, the aim of this study was to investigate trunk and gluteal muscle activation, pain, intensity and perceived exertion during aquatic and land exercises in people with and without CLBP.

[H1]Methods

Please see also supplementary online material, available at [https://academic.oup.com/ptj](https://academic.oup.com/ptj/advance-article-abstract/doi/10.1093/ptj/pzy150/5299588), for full methodological details on inclusion/exclusion criteria, exercise selection process and rationale, identification of repetition onset, participant familiarization, and EMG normalization and processing.

[H2]Participants

Power calculations using GPower 3.1²⁸ showed that for a power of 80% to detect a medium effect ($f = 0.25$, α -level = 0.05), a total sample of 34 participants would be required. Therefore, 20 males with non-specific CLBP for >12 weeks (33.1 ± 6.3 years, 1.81 ± 0.07 m, 82.6 ± 23.4 kg, BMI = 23.6 ± 1.9) and 20 males without MSDs and similar group characteristics to those of the CLBP group (28.5 ± 7.8 years, 1.78 ± 0.07 m, 77.5 ± 8.5 kg, BMI = 24.4 ± 2.3) volunteered for this study. The CLPB group characteristics for the Oswestry Disability Index questionnaire, the TAMPA scale for kinesiophobia and the STarT back screening (total and sub score) were respectively $21.1 \pm 11.5\%$, 32.5 ± 6.0 , 1.5 ± 1.2 and 0.7 ± 0.7 . Ethical approval was obtained from the institutional ethics committee. All

participants read the participant information sheet and signed an informed consent form before commencing the study.

[H2]Exercise Selection Process and Rationale

Exercises were selected based on appropriateness for rehabilitation, following a thorough multi-stage process that included open consultation with physiotherapists and beneficiaries. Body movements, instructions to participants and cadence were standardised. The 14 exercises with upper limb dynamic movements and 16 exercises with lower limb dynamic movements used in this study are described in Figure 1.

The land and water environments have some fundamental differences, such as that buoyancy acts in the opposite direction to gravity and that the water resistance is extremely difficult to replicate on land. Therefore, when selecting land exercises the intention was not to create identical conditions between the two environments- something that would probably be impossible. Instead, by selecting commonly used land rehabilitation exercises that have very similar movement patterns to those in the water, the aim was to provide comparisons that would be particularly useful for professional practice and would further inform rehabilitation programme prescription for both environments.

[H2]Experimental Setup

Aquatic testing took place in a 25-m indoor pool (depth = 1.25 m, average water temperature = 28°C). For EMG measurements, a 16-channel Mini-Wave Waterproof EMG system (Cometa SRL, Milan, Italy) was used. This system was wireless and waterproof, substantially reducing active drag and movement inhibition compared to systems with external cables connecting electrodes to amplifiers. Standard Ag-AgCl electrodes (Ambu Blue Sensor Electrode, Ambu Ltd, St Ives, UK) were placed on the skin on the left and right sides of the

body over the muscles erector spinae (ES), multifidus (M), rectus abdominis (RA), external oblique (OE), internal oblique (OI), gluteus maximus (GMax) and gluteus medius (GMed) using SENIAM guidelines²⁹ for spinal extensors and gluteal muscles and, in the absence of SENIAM guidelines, recommendations by Boccia and Rainoldi³⁰ and Huebner et al.³¹ for abdominal muscles. EMG data was sampled at 2000Hz. Aquatic exercises were recorded by two underwater and two above water cameras (ELMO PTC-400c, 25 Hz, synchronised and genlocked). Land exercises were recorded through a nine-camera Motion Capture system (Qualisys Inc., Gothenburg, Sweden, 100 Hz). These recordings were used to identify the onset of each repetition for subsequent EMG processing.

[H2]Data Collection

Participants undertook familiarization for the water and land exercises in separate sessions and on different days to those of the experimental data collection. On testing days, each participant performed a 5-min warm-up on a Monarch-814 bike (Monark Exercise AB, Vansbro, Sweden; power output of 30 watts at 60rpm), followed by 12 to 15 repetitions of the exercises subsequently used for the sub-maximal contractions at a self-selected comfortable intensity. The EMG electrodes were then applied and land-based sub-maximal isometric contractions performed for EMG data normalisation. Maximum voluntary isometric contractions (MViC) were not used to normalize EMG data, due to the limitations of obtaining MViC data in a LBP population³². For the main data collection, exercise order was randomised and data collected for 10 repetitions per exercise. The mean and peak EMG were calculated for repetitions 2-9. At the end of each exercise the rate of perceived exertion (RPE; Borg Scale, scored from 6-20), the intensity of exercise (heart rate (HR), beats per minute; Polar Monitor, Kempele, Finland) and, for the CLBP group, pain (visual analog scale, scored from 0-10), were also recorded.

[H2]Statistical Analysis

Data normality and homogeneity of variance were checked through Shapiro-Wilk and Levene tests ($\alpha = 0.05$). For each exercise, EMG comparisons between CLBP and control group and between water and land environments were made using Two-Way ANOVA with one between and one within factor (group \times environment). Bootstrapping for non-normal data was carried out using t-tests in the post-hoc investigation of Main Effects of group or environment. Because of the volume of comparisons, the post-hoc α -level was set at 0.01 to mitigate for the experiment-wise error rate. Post-hoc analyses were not carried out for the interactions as the ANOVA showed no significant differences. Effect sizes were calculated using partial eta squared, with small, medium and large effects classified as values of 0.0099, 0.0588, 0.1379.³³ Differences between CLBP and control groups for HR and RPE were carried out separately in water and land using independent t-tests ($\alpha = 0.05$). Pain data for land and water exercises were compared using non-parametric methods (Wilcoxon matched-pairs signed-rank tests; $\alpha = 0.05$) due to skewed distributions resulting from the many zero scores obtained.

[H2]Role of Funding Source

The present study was funded by the Chief Scientist Office in Scotland, project reference number ETM/378.

[H1]Results

Examples of EMG data recorded during the exercises are shown in Figures 2 and 3. Figure 2 illustrates the mean EMG data and Figure 3 the peak EMG data recorded in the water and land for Ex7 (hip abduction). Figures 4 and 5 (available as supplementary online material)

show the mean and peak EMG data for all exercises. The RPE, HR, and pain data are shown in Table 1.

[H2]Differences Between CLBP and Control Groups

In most cases, muscle activation, RPE and HR values were not different between the CLBP and control groups. The only exceptions were the mean ESL activations in Ex2 ($P = .007$; 95% CI = 0.59 to 4.83; partial eta squared = 0.105) and RPE in Ex6 ($P = .022$; 95% CI = 0.26 to 3.12; partial eta squared = 0.133), which were greater in the CLBP group.

[H2]Differences Between Aquatic and Land Environments

Significant differences between environments are shown in Table 2 for EMG and in Table 3 for HR and RPE. There were no differences in muscle activation between water and land in about two thirds of the cases. Significantly higher mean or peak activation for some muscles on land was observed in c.29% and in the water in c.5% of comparisons. Higher activation in the water was recorded for OEL and OER (Ex3, Ex5), for RAL (Ex3, Ex4), and for ES and RA (Ex11). With the exception of Ex5, higher activation on land was recorded for some muscles in all other exercises. Heart rate was higher on land for all exercises. Perceived exertion was higher in the water for three exercises (Ex2, Ex3, Ex5), higher on land for six exercises (Ex7L/R, Ex8L/R, Ex9L/R) and not different for the remaining six exercises.

[H2]Pain in the CLBP Group

Pain level was generally low and not significantly different between environments (water pain level = 1.8 ± 1.0 , land pain level = 2.4 ± 1.6). Pain was reported more than twice as frequently when exercising on land, with 23 reports of pain on land (7.7% of cases) and 11 reports of pain in the water (3.7% of cases).

[H1]Discussion

Low back pain affects millions of people worldwide and causes pain, disability and a decrease in quality of life. Although exercise is recommended for the treatment and management of CLBP, information on appropriateness of rehabilitative aquatic exercises in activating trunk and gluteal muscles was lacking. This is the first study to measure trunk and gluteal muscle activation in people with CLBP when performing rehabilitative aquatic exercises, and to report the associated pain, intensity and perceived exertion. The inclusion of similar land exercises and of a group of healthy controls, as well as the use of rigorous advanced methods, provide confidence in the findings and their practical applications. This robust set of data can positively affect practice, inform exercise prescription and improve effectiveness of rehabilitation.

In summary, the between-group comparison in the present study showed no differences between CLBP and control groups. The between-environment comparison revealed no differences in muscle activation in two thirds of the cases, but activation was higher on land in 29% and in the water in 5% of comparisons. Heart rate was higher on land than in the water, but perceived exertion showed a mixed pattern, with neither environment producing consistently higher values than the other. Pain levels were low but pain was reported more than twice as frequently when exercising on land.

[H2]Differences Between CLBP and Control Groups

The only significant differences between the two groups were the mean ES values for one exercise (out of 840 EMG comparisons) and RPE for one exercise (out of 30 comparisons). This is well within the experiment-wise error rate of false significant differences one could expect due to possible statistical Type 1 error (approximately eight false significant

differences for EMG and two for RPE). Hence, it can be stated that participants with CLBP had the same muscle activation, HR and perceived exertion as healthy controls when exercising in the water and land. As this is the first such dataset for an aquatic environment, it suggests that exercising in the water can be beneficial for rehabilitation and strengthening by allowing people with CLBP to perform the exercises and activate muscles without their condition adversely affecting them.

In previous studies comparing muscle activity between CLBP and control groups during similar land exercises, c.80% of the comparisons showed no differences.³⁴⁻³⁶ When differences were reported the patterns were mixed, at times even within the same exercise, with no group displaying consistently higher activation. Ng et al.³⁵ stated that this possibly relates to the variance in impaired coordination of people with CLBP and the fact that trunk muscles may act as prime movers, antagonists or stabilisers. In line with some of their findings, and considering that several different exercises have been tested among studies, it is also possible that slight variations in exercises may elicit different patterns of activation for some muscles in CLBP groups.

It is worth noting that in the present study participants with CLBP exercised recreationally despite their CLBP, and were classified as having moderate disability and low risk on kinesiophobia. This implies that they would typically respond well to self-management³⁷ and may further explain the absence of between-group differences. It has been suggested that sub-grouping people with LBP based on clinical findings may be useful in helping select the most appropriate treatment.³⁸ Thus, future research should seek to confirm if the current findings reflect CLBP populations with greater disability and/or fear of movement, or even a sub-group of acute sudden onset pain.

[H2]Differences Between Aquatic and Land Environments

[H3]Muscle activation. No significant differences were found between environments in c.66% of all muscle activation comparisons. There was greater activation on land in c.29% of comparisons and greater activation in the water in the c.5% of comparisons.

Mean Ex1 activity was greater on land for the contralateral spinal extensors, whereas the ipsilateral spinal extensors were not significantly different. There was not the same consistency for the remaining muscles, as activation was greater on land for three of the four oblique abdominal muscles in Ex1L, but just one in Ex1R. One of the reasons for the side differences could be that there were three reports of pain for Ex1R on land but none in the water. Interestingly, Ex2 showed differences for the gluteal muscles only (higher on land), suggesting that hydrostatic pressure probably offers sufficient support to maintain balance during sagittal upper limb movement despite the drag and turbulence created. Ex3 and Ex5 that incorporated alternating upper limb movements required similar activation in the water and land for the spinal extensors and majority of gluteal muscles (except OE activation being higher in the water). Greater activation on land was needed in spinal extensors and gluteal muscles for Ex4, which involved a movement assisted by gravity (land) or buoyancy (water) in the first phase. Hence, performing a squat with upper limb movement, similar to a lifting task, is perhaps initially better trained in an aquatic environment if spinal extensor over-activity is problematic or painful. Ex6 might pose similar benefits, due to greater abdominal and spinal extensor activity on land. If an abdominal strengthening exercise was required for rehabilitation but a land programme was too advanced, then this water exercise may offer a suitable intermediate step.

In the unilateral lower limb exercises of hip abduction, extension and single-leg squat (Ex7-9), gluteal activity was the same or greater on land. This may not be surprising due to the effects of buoyancy assisting the concentric phase, which would normally require

increased gluteal effort in the dynamically moving lower limb on land to control against gravity. In addition, hydrostatic pressure offers greater support in the water, thereby attenuating the need for gluteal activity to maintain balance in the static supporting lower limb. These might suggest that to increase gluteal activity unilateral hip exercises should be performed on land rather than in the water, as gluteal weakness has been observed in patients with CLBP.^{11,39} The ES and RA had greater activation in the water for Ex11, perhaps suggesting a greater ‘splinting’ or co-activation of the large force-producing sagittal trunk muscles. Such a trunk stiffening strategy has been observed in people with LBP⁴⁰ and may not be desirable. However, it is also possible that the ES and RA activity implied abdominal bracing, as with the body being partially supported by the dumbbells muscles such as the latissimus dorsi and iliopsoas may have been activated more. Finally, another possibility is that the water alternative of this exercise required greater postural control due to buoyancy effects displacing the dumbbells, thus making it more challenging. In this case, the aquatic version of the exercise could be considered as a progression of the land exercise.

Overall, muscle activation in the water was at least similar to that on land in 71% of all muscle comparisons. This is contrary to some previous research findings and assumptions that aquatic exercise produces lower muscle activation^{22,24}. It is important to note that lower activation in the water in previous research had sometimes been partially attributed to the challenges of waterproofing electrodes, which could cause a decrease in the recorded EMG values in the water. The EMG system in the present study was waterproof by design, minimising such problems. Introducing an element of added resistance in several of the aquatic exercises in the present study could also be another reason that, contrary to previous assumptions, activation in the water was usually not lower than that on land. This suggestion is in line with some findings in other studies, where higher muscle activity had often been reported when resistance was added in aquatic exercises.^{24,25} Although research findings in

this area should always be interpreted with caution given the limitations of comparing aquatic and land exercises, the present data suggest that aquatic exercise should not be regarded to be less effective than land exercise in activating trunk and gluteal muscles. The level of activation may be muscle-, exercise- or resistance-dependant. Finally, as summarised by Bressel et al.²², levels of activation of 25% or less have been shown to be sufficient to improve motor control and endurance aspects of some trunk muscles and are a level of intensity that maximally stiffens segmental joints of the spine. Thus, the exercises that were used in the present study seem to overall produce sufficient levels of activation for subsequent improvements.

[H3]Heart rate and perceived exertion. Heart rate was lower in the water. This was anticipated as water immersion is generally expected to reduce HR.⁴¹ Although comparison of HR values in the water and land has been previously reported in other studies,⁴¹ the present study is the first in this area to compare perceived exertion between these two environments. A mixed pattern was observed, with no environment producing consistently higher values than the other. Perceived exertion scores for individual participants ranged from 6 to 19 ('no exertion' to 'extremely hard') in both environments. In some exercises, when higher exertion was recorded in one environment there were also more muscles with higher activation in that environment. However, in most exercises higher perceived exertion for an environment was not accompanied with higher muscle activation, so differences in muscle activation did not seem to be linked to differences in perceived exertion.

[H3]Pain in the CLBP group. Pain level was generally low and not different between environments, despite a tendency for the non-zero values to be higher on land (2.4 vs 1.8). Pain was reported more than twice as often on land (7.7%) than in the water (3.7%),

suggesting that an aquatic environment may be more appropriate than land for avoiding the adverse effects of pain when exercising. Pain level has been reported to be either similar between environments or lower in the water in previous studies^{13,18}, with one study reporting that the aquatic environment produced about half the reports of pain of the land environment.¹⁷

Right hip extension was the only aquatic exercise to have more than two pain reports, with pain level though being very low (1.0). On the contrary, at least three participants (\geq 15% of the group) reported pain in one third of all land exercises (mean level from 1.6-3.5). Although this requires further investigation to be confirmed for other CLBP groups, such findings are potentially relevant for patients with CLBP of higher severity or irritability of symptoms, where exercising in water may be the only medium where pain can be maintained under a manageable threshold. It is also possible that the water provided better support in exercises such as Ex8, helping maintain a more stable and neutral trunk and pelvis.

[H2]Limitations and Future Directions

We examined a male CLBP population that had mild-to-moderate disability, using exercises with specific cadence and resistance. Future studies could expand to participants of both genders with different levels of disability and classification, and explore any differences when resistance or speed of movement are altered. The exercises in the present study should now be used inform rehabilitation programmes in the water and land and to evaluate their effectiveness and cost-effectiveness compared with other types of CLBP treatment and management.

[H2]Conclusion

There were no differences between people with and without CLBP when exercising in the water or land. For the between-environment comparison, HR was higher on land but no environment produced consistently higher values than the other for perceived exertion. Muscle activation was different between environments in about one third of comparisons (greater on land in 29% and in the water in 5% of cases). This diversity indicates that aquatic exercises should not be assumed to be less strenuous or less effective in activating muscles than land exercises. Pain was reported more than twice as frequently when exercising on land, suggesting that the aquatic environment may be more appropriate for patients with kinesiophobia or when pain is a limiting factor.

Author Contributions

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Ethics Approval

Ethical approval was obtained from the ethics committee of the Moray House School of Education, at the University of Edinburgh. All participants read the participant information sheet and signed an informed consent form before commencing the study.

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Disclosures

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

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- 42.

Figure Legends























Aquatic Exercises		Land Exercises	
Description	Photo	Description	Photo
1L and 1R (performed separately): Hold a disc (23cm diameter) between the hands just below water surface with arms fully outstretched in front. Rotate the trunk steadily as far to one side as possible and back to midline (35 bpm).		1L and 1R (performed separately): Hold a Swiss ball (55cm diameter) between the hands with arms fully outstretched in front at chest height. Move the ball steadily as far to one side as possible and back to midline (35 bpm).	
2: Hold a kicking board (34x24cm) vertically with arms fully outstretched just below water surface. Move the arms backwards towards the body and forwards to the starting position (45 bpm).		2: Hold a Swiss ball (55cm diameter) with arms fully outstretched in front at chest height. Bring it close the chest and then return to starting position (45 bpm).	
3: Hold buoyant discs (12.5cm diameter) in each arm just below water surface, the left close to the body and the right fully outstretched. Perform alternate reciprocal punching actions with the arms (45 bpm).		3: Hold a blue Theraband in each hand passing round the trunk level at the middle of the thoracic spine. Alternately fully outstretch the arms, similar to a punching action (45 bpm).	
4: Have arms by the sides with forearms pronated and paddles (12.5x20cm) strapped to the hands. Bring the arms together to just below water surface while flexing the knees to a squat. Return to starting position (45bpm).		4: Hold a Swiss ball (55cm diameter) above the head with arms fully extended. Move the ball to chest height while performing a squat with the lower body. Return to starting position. (45 bpm).	
5: Have the left arm by the side and the right arm outstretched in front, just below the surface, with forearms supinated and paddles strapped to the hands. Bring the left arm to just below water surface and simultaneously the right arm to the side. Return to starting position (30 bpm).		5: Have the arms by the side of the body and hold the two ends of a blue Theraband passing behind the body under the gluteal fold. Move alternately each arm upwards to chest height and back to starting position (30 bpm).	
6: Have the trunk in an upright position, arms outstretched and hands resting on the surface holding dumbbell floats. Move dumbbells forwards slowly with the body in a neutral posture tilting on the tips of the toes. Return to starting position maintaining neutral body posture (12bpm).		6: Kneel on the ground in an upright posture with hands resting on a Swiss ball (65cm diameter). Roll the ball forwards slowly until forearms are resting on it and shoulders are above elbows. Roll back to starting position maintaining a neutral body posture (20 bpm).	
7L and 7R (performed separately): Stand on one leg with arms abducted at 45°. Abduct the opposite leg as far as possible, retaining a neutral position throughout (avoid external rotation). Return to starting position (45bpm).		7L and 7R (performed separately): Same as aquatic exercises 7L and 7R.	
8L and 8R (performed separately): Stand on one leg with arms abducted at 45°. Perform hip extension maintaining the lower limb in a neutral position (avoid external hip rotation). Return to starting position (45bpm).		8L and 8R (performed separately): Same as aquatic exercises 8L and 8R.	
9L and 9R (performed separately): Stand on one leg with arms crossed at chest, the non-weight bearing limb in a neutral position with the knee flexed to 90°. Perform single leg squat on the weight-bearing limb so that the knee moves just in front of the toes (50bpm).		9L and 9R (performed separately): Same as aquatic exercises 9L and 9R, but with arms by the side.	
10: Stand on both legs with arms by the side. Take a large step to one side keeping the knee extended, then bring the other leg next to it. Repeat to the other side (65bpm).		10: Same as aquatic exercise 10, but with a blue Theraband tied round the ankles (40bpm).	
11: Hold dumbbell floats in each hand and position the arms by the side. Raise the knees alternately until thighs are parallel to the water surface (30bpm).		11: Sit on a Swiss ball (65cm diameter) with knees positioned at 90° and arms by the side without the hands touching the ball. Raise the feet alternately from the ground to a height of approximately 20cm (30bpm).	

Figure 1: Description of the aquatic and land exercises used in the present study. For Ex 1-5, participants had the same starting position for water and land, with feet shoulder width apart and knees in slight flexion (between 15-30°). This lower limb position with a static pelvic posture was maintained throughout the exercises (except Ex4 where the static foot position only was maintained). For Ex 7-11, the participants were instructed not to move their trunk.

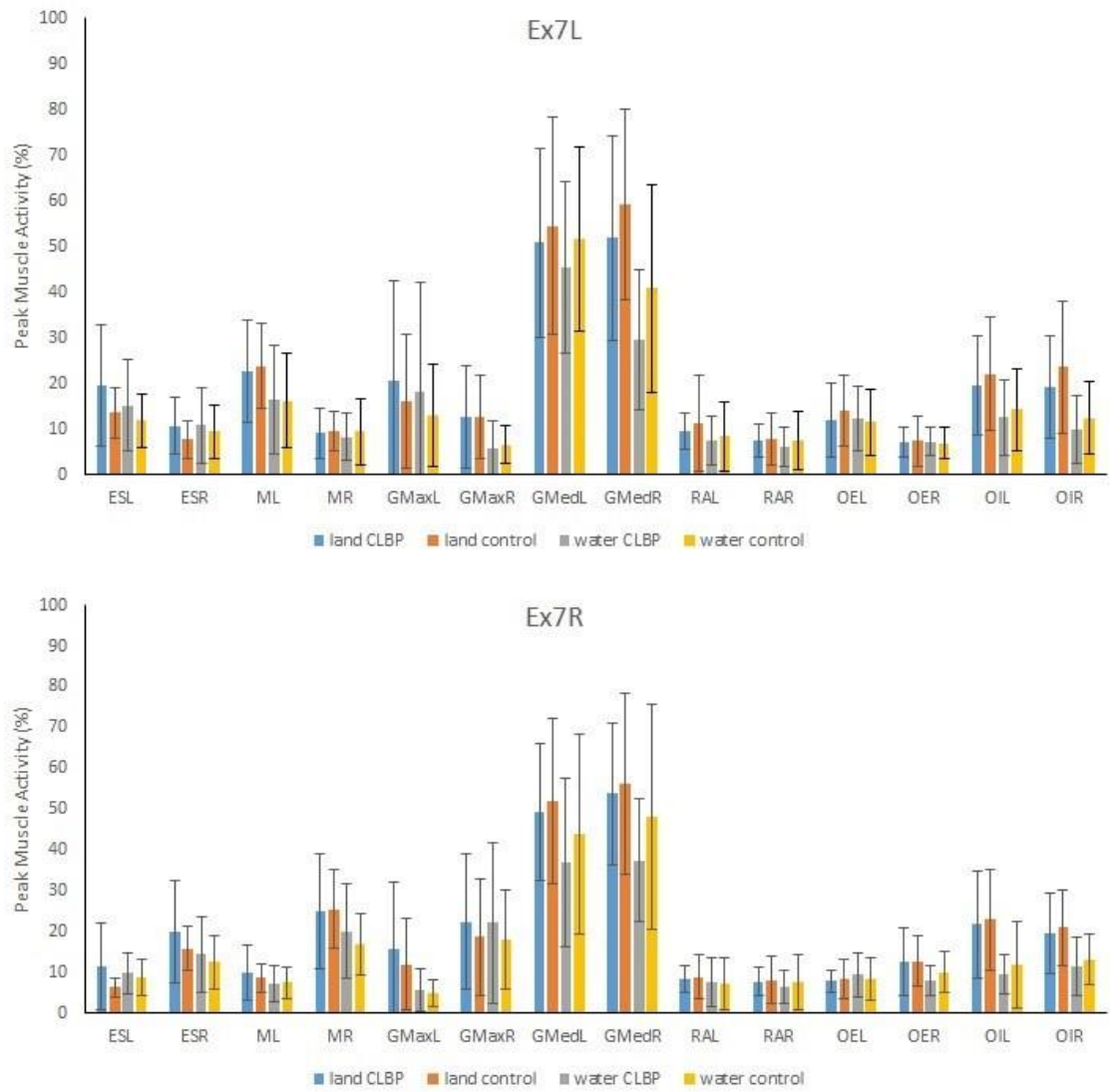


Figure 2: Mean muscle activity for the CLBP and control groups during dynamic lower limb exercise 7 (hip abduction).

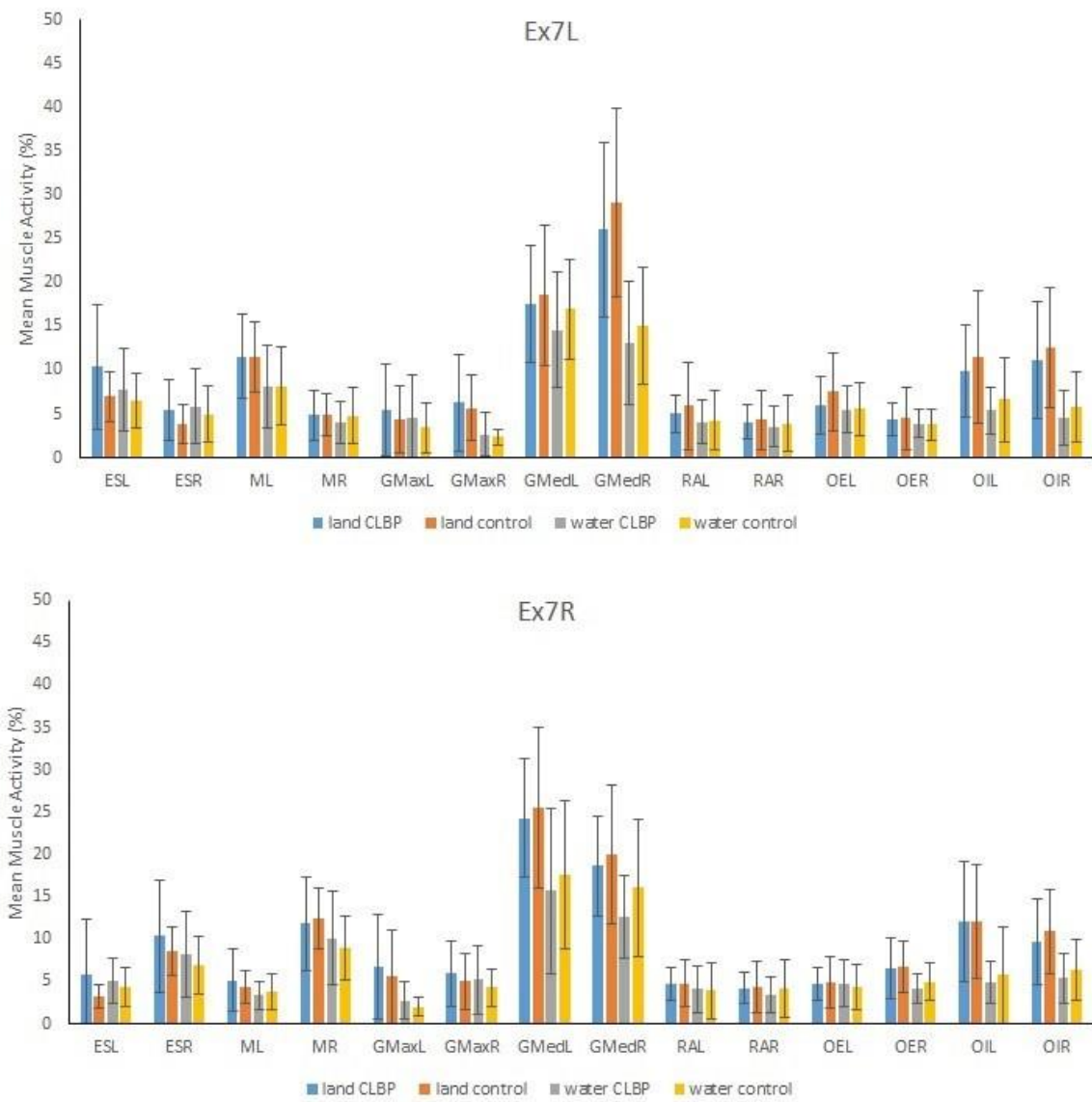


Figure 3: Peak muscle activity for the CLBP and control groups during dynamic lower limb exercise 7 (hip abduction).

Table 1.Heart Rate (HR), Rate of Perceived Exertion (RPE),^a and Pain.

Water Exercises					Land Exercises						
Exer cise	HR ^b		RPE ^c		Pain ^d	Exer cise	HR ^b		RPE ^c		Pain ^d
	CLBP Group	Control Group	CLBP Group	Control Group	CLPB Group		CLBP Group	Control Group	CLBP Group	Control Group	CLPB Group
1L	75 (8)	70 (11)	10 (2)	9 (2)	3.4, 3.8	1L	86 (9)	89 (15)	11 (2)	10 (2)	0.9, 1.1, 1.4, 3.3
1R	73 (8)	68 (13)	10 (2)	10 (2)		1R	89 (9)	90 (15)	10 (2)	10 (2)	1.3, 1.34
2	75 (9)	70 (14)	10 (2)	10 (2)	2.6	2	85 (11)	85 (13)	8 (2)	8 (2)	2.9
3	77 (9)	73 (11)	10 (2)	9 (2)	1.8	3	82 (11)	82 (15)	9 (2)	9 (2)	6.9
4	85 (7)	81 (11)	11 (2)	10 (2)		4	100 (10)	99 (16)	12 (2)	11 (2)	1.6, 1.6
5	79 (10)	76 (12)	11 (3)	10 (2)		5	85 (10)	89 (11)	10 (2)	9 (2)	1.1
6	74 (11)	68 (11)	14 (3)	12 (3)		6	91 (9)	90 (12)	13 (2)	12 (3)	1.5
7L	76 (11)	72 (12)	9 (2)	9 (2)	1.4	7L	87 (10)	88 (13)	11 (2)	11 (2)	1.5
7R	76 (9)	73 (12)	10 (2)	9 (2)	0.8, 1.9	7R	87 (8)	90 (15)	11 (2)	10 (2)	1.8, 2.2
8L	68 (9)	70 (12)	9 (2)	9 (2)	1.2	8L	85 (8)	88 (13)	10 (2)	9 (2)	1.8, 1.8
8R	69 (9)	70 (13)	9 (2)	9 (2)	0.9, 1.1, 1.1	8R	85 (8)	89 (15)	10 (2)	9 (2)	1.4, 1.1, 2.1
9L	75 (11)	72 (14)	10 (2)	10 (2)		9L	89 (9)	94 (14)	12 (2)	11 (3)	1.5
9R	76 (10)	74 (12)	10 (2)	10 (3)		9R	89 (9)	92 (14)	12 (2)	11 (3)	1.5
10	80 (12)	82 (11)	10 (3)	11 (3)		10	88 (11)	90 (14)	11 (3)	10 (2)	1.5, 1.3, 4.2
11	74 (11)	70 (13)	11 (3)	11 (3)		11	80 (8)	80 (12)	12 (2)	10 (3)	1.5

^aAs recorded at the end of dynamic exercises with upper limb (exercises 1–6) and lower limb

(exercises 7–11) movements. Values are reported as mean (SD) unless otherwise indicated. CLBP = chronic low back pain; L = left side; R = right side.

^bReported as beats/minute.^cReported as scores on the Borg Scale (from 6 to 20).^dPain values shown are all of the non-zero values reported (on the visual analog scale, scored from 1 to 10), with blank cells indicating no pain report.

Table 2.

Significant Differences Between Land and Water Environments in Mean and Peak Electromyographic (EMG) Amplitudes for Dynamic Exercises^a

Exercise	Muscle ^b	Significant Differences ^c in:					
		Mean EMG			Peak EMG		
		<i>P</i>	95% CI	Effect Size	<i>P</i>	95% CI	Effect Size
1L	ESR	.001	-6.68 to -3.56	0.529			
	MR	.001	-4.70 to -1.97	0.358			
	GMaxR	.001	-1.39 to -0.40	0.268			
	GMedR	.001	-2.06 to -0.71	0.284			
	OER	.001	-7.49 to -2.63	0.297			
	OIL	.001	-7.59 to -3.15	0.384			
	OIR	.001	-4.63 to -1.94	0.391	.006	-8.32 to -1.69	0.238
1R	ESL	.001	-6.89 to -3.58	0.493	.004	-8.14 to -2.19	0.234
	ML	.001	-5.80 to -2.52	0.415	.001	-8.00 to -1.60	0.250
	GMedL	.003	-3.49 to -1.18	0.295			
	OIR	.008	-8.39 to -2.95	0.309			
2	GMaxL	.004	-1.44 to -0.41	0.266			
	GMaxR	.001	-1.65 to -0.65	0.384	.001	-2.43 to -0.87	0.293
	GMedL	.002	-2.22 to -0.78	0.284	.008	-3.11 to -0.89	0.201
	GMedR	.001	-1.98 to -0.84	0.381	.003	-2.75 to -0.84	0.254
3	GMedR	.002	-1.59 to -0.58	0.283			
	RAL	.008	0.57 to 2.11	0.220	.003	1.97 to 5.48	0.257
	OEL	.004	1.64 to 3.85	0.349	.002	3.43 to 7.98	0.362
	OER	.009	1.10 to 2.80	0.269	.004	2.29 to 6.11	0.277
4	OIR	.005	-2.78 to -0.60	0.219			
	ESL	.001	-8.37 to -3.62	0.425	.002	-16.64 to -5.06	0.265
	ESR	.001	-9.26 to -4.10	0.373			
	ML	.001	-7.55 to -4.10	0.536	.001	-17.07 to -8.39	0.387
	MR	.001	-8.88 to -4.89	0.572	.001	-21.57 to -11.41	0.444
	GMaxL	.001	-3.75 to -2.26	0.625	.001	-12.74 to -7.91	0.637
	GMaxR	.001	-3.61 to -2.44	0.715	.001	-12.53 to -8.20	0.728
	GMedL	.001	-3.18 to -1.28	0.358	.001	-9.88 to -3.89	0.404
	GMedR	.001	-2.79 to -1.08	0.341	.001	-8.74 to -3.62	0.323
RAL	.001	3.07 to 6.91	0.418	.001	19.17 to 36.46	0.476	
5	OEL	.001	1.98 to 3.72	0.437	.002	4.34 to 8.80	0.454
	OER	.002	1.69 to 3.35	0.442	.001	3.90 to 8.38	0.465
6	ESL	.005	-4.20 to -1.37	0.299			

	ESR	.002	-4.91 to -1.85	0.288			
	ML	.002	-2.10 to -0.74	0.345			
	MR	.001	-2.83 to -1.28	0.439	.001	-5.65 to -1.85	0.336
	RAL	.001	-35.29 to -8.76	0.517	.001	-139.60 to -72.92	0.556
	RAR	.001	-24.8 to -12.7	0.521	.001	-95.11 to -54.98	0.602
	OER	.002	-7.78 to -1.68	0.242	.002	-27.94 to -6.31	0.267
	OIL	.001	-13.90 to -7.90	0.559	.001	-48.82 to -26.05	0.571
	OIR	.001	-15.82 to -8.38	0.545	.001	-58.28 to -29.99	0.491
7L	ML	.001	-5.00 to -1.74	0.288	.001	-10.32 to -3.65	0.290
	GMaxR	.001	-5.15 to -2.06	0.357	.002	-10.01 to -3.38	0.291
	GMedR	.001	-16.98 to 10.10	0.569	.002	-28.90 to -12.15	0.343
	OIL	.001	-6.91 to -2.93	0.376	.001	-11.27 to -4.14	0.323
	OIR	.001	-8.53 to -5.15	0.570	.001	-14.07 to -6.95	0.417
7R	MR	.001	-3.85 to -1.40	0.307	.001	-9.18 to -4.29	0.411
	GMaxL	.004	-5.59 to -2.04	0.352	.007	-12.66 to -4.70	0.342
	GMedL	.001	-11.38 to -4.99	0.349			
	GMedR	.003	-7.31 to -2.77	0.301			
	OER	.002	-3.32 to -1.31	0.361			
	OIL	.001	-8.85 to -4.88	0.500	.001	-15.70 to -8.00	0.451
	OIR	.001	-5.90 to -3.37	0.535	.001	-10.77 to -5.86	0.515
8L	ML	.009	-4.04 to -0.62	0.175			
	GMaxL	.006	-3.79 to -0.60	0.184			
	GMaxR	.002	-2.14 to -0.73	0.250			
	GMedR	.001	-14.42 to -9.06	0.677	.001	-24.09 to -14.24	0.589
	OIL	.001	-6.76 to -3.43	0.450	.001	-11.85 to -5.33	0.385
	OIR	.001	-7.41 to -4.41	0.574	.002	-11.40 to -6.21	0.524
8R	GMaxR	.008	-3.73 to -0.60	0.170			
	GMedL	.001	-9.70 to -5.71	0.591	.001	-14.43 to -6.27	0.400
	GMedR	.004	-5.84 to -1.43	0.251			
	OER	.003	-1.88 to -0.63	0.283	.007	-3.31 to -0.78	0.201
	OIL	.002	-7.75 to -4.15	0.495	.001	-12.56 to -6.24	0.453
	OIR	.001	-5.60 to -2.94	0.506	.001	-9.80 to -4.93	0.462
9L	GMaxL	.001	-4.45 to -2.07	0.426	.001	-10.12 to -3.67	0.347
	GMedL	.001	-12.21 to -6.92	0.581	.001	-20.43 to -8.84	0.392
	OIL	.001	-7.23 to -3.61	0.443	.001	-11.95 to -4.80	0.354
	OIR	.001	-3.98 to -2.02	0.490	.001	-5.97 to -2.69	0.410
9R	GMaxR	.001	-5.25 to -2.82	0.496	.002	-10.99 to -4.72	0.377
	GMedR	.001	-15.99 to -9.58	0.602	.001	-26.88 to -11.33	0.338
	OIL	.001	-5.29 to -2.05	0.315	.001	-8.35 to -2.83	0.296
	OIR	.001	-7.44 to -4.10	0.619	.001	-12.18 to -5.93	0.534
10	OIL	.001	-7.57 to -3.87	0.460	.002	-19.83 to -9.44	0.441
	OIR	.001	-7.44 to -3.79	0.520	.001	-20.72 to -10.85	0.549
11	ESL	.001	2.43 to 5.32	0.390	.005	1.94 to 7.39	0.231

	ESR	.002	2.49 to 6.09	0.328	.008	0.95 to 8.17	0.184
	MR				.004	-3.58 to -0.56	0.201
	GMedR	.001	-3.04 to -1.33	0.376	.001	-9.20 to -3.55	0.349
	RAL	.001	3.13 to 6.14	0.510	.001	5.84 to 10.67	0.507
	RAR	.001	3.66 to 7.02	0.520	.001	6.44 to 12.44	0.547

^aExercises included upper limb (exercises 1–6) and lower limb (exercises 7–11) movements.

^bESL = left erector spinae; ESR = right erector spinae; GMaxL = left gluteus maximus; GMaxR = right gluteus maximus; GMedL = left gluteus medius; GMedR = right gluteus medius; ML = left multifidus; MR = right multifidus; OEL = left external oblique; OER = right external oblique; OIL = left internal oblique; OIR = right internal oblique; RAL = left rectus abdominis; RAR = right rectus abdominis

^cNegative 95% CIs indicate greater EMG amplitudes on land. Positive 95% CIs (shown in bold type) indicate greater EMG amplitudes in water. Empty cells indicate no significant difference.

Table 3.

Significant Differences Between Land and Water Environments in Heart Rate and Rate of Perceived Exertion During Dynamic Exercises^a

Exercise	Significant Differences ^b in:					
	Heart Rate			Rate of Perceived Exertion		
	<i>P</i>	95% CI	Effect Size	<i>P</i>	95% CI	Effect Size
1L	<.001	10.05 to 19.35	0.533			
1R	<.001	13.07 to 24.11	0.565			
2	<.001	7.64 to 16.13	0.465	<.001	-2.63 to -0.94	0.331
3	<.001	2.91 to 12.08	0.228	.001	-1.09 to -0.13	0.151
4	<.001	12.44 to 20.83	0.643			
5	<.001	4.57 to 13.65	0.321	.033	-1.35 to -0.06	0.117
6	<.001	16.87 to 26.32	0.705			
7L	<.001	6.63 to 17.24	0.559	<.001	0.79 to 2.27	0.320
7R	<.001	10.05 to 17.68	0.594	.001	0.63 to 2.08	0.278
8L	<.001	13.76 to 20.57	0.744	.046	0.01 to 1.42	0.103
8R	<.001	13.42 to 20.81	0.711	.026	0.09 to 1.38	0.127
9L	<.001	12.90 to 22.73	0.600	.001	0.92 to 2.49	0.344
9R	<.001	10.10 to 19.18	0.543	<.001	0.63 to 2.26	0.259
10	<.001	3.16 to 12.57	0.237			
11	<.001	4.32 to 12.24	0.347			

^aExercises included upper limb (exercises 1–6) and lower limb (exercises 7–11) movements. L = left side; R = right side.

^bHeart rates were always significantly higher on land. Rates of perceived exertion were significantly higher on land unless indicated otherwise. Rates of perceived exertion shown in bold type were significantly higher in water. Empty cells indicate no significant difference.