Physiotherapy 116 (2022) 108–118

The WATER study: Which AquaTic ExeRcises increase muscle activity and limit pain for people with low back pain?

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Abstract

Objective Aquatic exercise therapy is used for the treatment and management of chronic low back pain (CLBP). However, to the authors' knowledge, no studies to date have compared muscle activity between different aquatic exercises performed by people with CLBP. As such, this study assessed and compared muscle activity, pain, perceived exertion and exercise intensity between different rehabilitative aquatic exercises.
Design Cross-sectional.
Setting A 25-m indoor swimming pool within a university building.
Participants Twenty participants with non-specific CLBP.
Assessment Twenty-six aquatic exercises in shallow water (1.25-m depth). Muscle activity was quantified bilaterally for the erector spinae, multifidus, gluteus maximus and medius, rectus abdominis, and external and internal obliques.
Main outcomes Mean and peak muscle activity, pain (visual analogue scale), perceived exertion (Borg scale) and exercise intensity (heart rate).
Results Hip abduction/adduction and extension/flexion exercises produced higher activity for gluteal muscles. Variations of squat exercises increased the activity of back extensors. Higher abdominal muscle activity was produced with exercises that made use of buoyancy equipment and included leg and trunk movements while floating on the back, and with some proprioceptive and dynamic lower limb exercises. Pain occurrence and intensity were very low, with 17 exercises being pain free.
Conclusions This study provides evidence on trunk and gluteal muscle activity, pain, intensity and perceived exertion for people with CLBP performing aquatic exercises. The findings may be useful when prescribing exercises for rehabilitation, as physiotherapists seek to implement progression in effort and muscle activity, variation in exercise type, and may wish to target or avoid particular muscles.

Contribution of the Paper

- This is the first study to compare trunk or gluteal muscle activity between 26 different aquatic rehabilitative exercises performed by people with CLBP.
- Pain occurrence and intensity of aquatic exercises are very low, with most exercises being completely pain free.
- The following aquatic exercises are particularly effective in increasing muscle activity: (a) hip abduction/adduction and extension/flexion exercises for gluteus maximus and medius; (b) squat exercises for back extensors (erector spinae and multifidus); and (c) exercises that make use of support buoyancy equipment and include leg movements while floating on the back for abdominals (rectus abdominis, and external and internal obliques).

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https://doi.org/10.1016/j.physio.2022.03.003

Keywords: Rehabilitation; Hydrotherapy; Physiotherapy; Musculoskeletal; Biomechanics

Introduction

Low back pain (LBP) is the most common musculoskeletal disorder, affects people of all ages, places a major burden on global health and has a high economic cost [1,2]. Eighty-five percent of all cases of LBP are non-specific, which is defined as LBP not attributable to a recognisable, known specific pathology [3]. Recurrence and chronicity are common, with > 60% of patients still experiencing pain 1 year after an acute LBP episode, and lifetime prevalence of chronic LBP (CLBP) of approximately 23% [1,4].

Guidelines for treatment and management of LBP commonly include recommendations for exercise [5,6]. Although it remains unknown whether a specific type of exercise is preferable in the management and treatment of LBP [7,8], exercise programmes on land and in the water have been shown to be beneficial in reducing pain and disability, and improving muscle function and strength [9–11]. Programmes may include general aerobic and strengthening exercises, and also exercises that target the recruitment of specific muscles to improve lumbopelvic stability, as altered neuromotor control of the spine and pelvis [12], and generalised weakness around the hip and abdominal muscles have been identified in this population [13]. Recent research on people without a history of LBP showed that the likelihood of developing LBP during a prolonged standing task was higher for people with increased bilateral co-activation and reduced endurance of the gluteus medius during that task, and suggested that appropriate targeting of gluteal muscles is recommended for the treatment and prevention of LBP [14,15]. Thus, information on the level of muscle activity when exercising is important for prescription and progression of rehabilitation programmes. Muscle activity should be of a sufficient level for muscle strengthening and avoidance of muscle atrophy. However, sometimes high levels of activity may be undesirable as they may increase the risk of back pain or injury [16]; on these occasions, lower activity may be preferable.

Marshall et al. [17] stated that the uncertainty in exercise prescription for CLBP rehabilitation can be attributed, in part, to the lack of information on muscle activity during exercise in patients with CLBP. Although some studies on rehabilitative exercises have included people with CLBP [18–20], most research in this area has been performed on asymptomatic individuals. Moreover, to the authors' knowledge, no studies have been undertaken in an aquatic environment to compare muscle activity between different exercises for people with CLBP. Exercising in the water has some important benefits compared with land-based exercise, as buoyancy and hydrostatic pressure reduce spine and joint loads, and may facilitate balance, mobility and pain control [21,22]. Research has shown that physiological effects of water immersion include increased cardiac output and cerebral blood flow [23,24], and potentially reduced heart rate (HR) and pain [25]. Aquatic exercise has been reported to lead to similar [9] or greater improvements [10,26,27] compared with land-based programmes, and may be more appropriate than land-based exercise for people with CLBP, particularly in the initial stages of rehabilitation and for those who have difficulties performing land-based exercise [21,22].

Improved methods of data collection in this area would assist in overcoming limitations in aquatic exercise studies that relate to: small number of trunk exercises used in studies with healthy participants [21,28]; active drag and movement inhibition caused by electromyography (EMG) systems with external cables connecting electrodes to amplifiers; and recording muscle activity on a single side of the body. Such improvements would increase confidence in the applicability and generalisability of the findings, and inform exercise selection and programme prescription by physiotherapists and health professionals. This could subsequently lead to improved quality of aquatic exercise for rehabilitation. Finally, to further improve programme design, it would be beneficial to include additional outcomes that are clinically relevant and/or may affect participant engagement and experience in aquatic studies. Such outcome measures could include any pain that may be experienced when exercising, the subjective exertion and the intensity of the exercises performed.

The purpose of this study was to quantify trunk and gluteal muscle activity during 26 rehabilitative aquatic exercises in people with CLBP, and to compare the activity of each muscle between different exercises. Additional outcome measures were pain, perceived exertion and exercise intensity.

Methods

Participants

Twenty males with non-specific CLBP volunteered to participate in this study. Power calculations using GPower 3.1 indicated that this sample was sufficient, as 12 participants would provide power of 95% to detect a medium effect (f=0.25, α-level=0.05). Inclusion criteria were: age 18–45 years; BMI < 28 kg/m^2; and CLBP > 12 weeks. Exclusion criteria were: illness; hydrotherapy contra-indications; other musculoskeletal disorders; abdominal or spinal surgery; spinal fractures; specific or acute CLBP; experiencing referred pain or other neurological sign; undergoing treatment for CLBP; taking strong analgesics or muscle relaxants; and score > 60% on the Oswestry Disability Index questionnaire. The participants completed the TAMPA scale for kinesiophobia and the STarT back screening tool. All participants read the participant information sheet and signed an informed consent form before commencing the study.

Protocol

The process of exercise selection and data collection has been detailed elsewhere [24], with key details provided in the online supplementary material. In brief, testing took place in an indoor swimming pool (water temperature 28°C, water depth 1.25 m). Twenty exercises were selected, six of which were performed separately to the right and left, providing a total of 26 exercises (Table 1). On the day of testing, following a warm-up, waterproof and wireless EMG sensors (Cometa SRL, Milan, Italy) were placed on the skin over the left and right sides of the erector spinae (ES), multifidus (MF), rectus abdominis (RA), external oblique (EO), internal oblique (OI), gluteus maximus (GMax) and gluteus medius (GMed) using recommended guidelines [29–31]. Participants performed five land-based exercises three times with 3-second holds to obtain sub-maximal isometric contraction values for subsequent EMG data normalisation [4].

For the main data collection, 10 repetitions of each exercise were performed. EMG data were processed, amplitude-normalised to the sub-maximal isometric contraction values, and time-normalised to 100%. Peak and mean EMG amplitude were identified for Repetitions 2–9 of each exercise. Exercise intensity [HR in beats per minute (bpm); Polar Monitor, Kempele, Finland], rate of perceived exertion (RPE, Borg's 6–20 scale) and pain (visual analogue scale, 0–10) were recorded at the end of each exercise. The methods that were used to assess the outcome measures in the present study have been shown to have high validity and reliability [32–35].

Statistical analysis

For each muscle, the mean EMG signals for all 26 exercises were compared. This was repeated for the peak EMG signal. Pain, HR and RPE scores for all exercises were also compared. Data normality was checked using Shapiro–Wilk tests. For normally distributed data, significant differences (α=0.05) between all 26 exercises were calculated using one-way analysis of variance with one repeated factor (exercise). If the sphericity assumption was violated, the Greenhouse–Geisser adjustment was applied. If the main effect of exercise was significant, Post-hoc t-tests (with a Bonferroni correction factor) were carried out between all pairs of exercises. For non-normally distributed data, differences between exercises were examined using the Friedman test, and if this was significant, post-hoc Wilcoxon matched pairs signed ranks tests were performed. As there were 325 Wilcoxon post-hoc tests in total, the α-level was set at 0.001 to control for experimental error rate. A true Bonferroni correction for all post-hoc tests would have used an α-level of 0.00015, but a value this low could lead to a large number of type 2 statistical errors (false-negative results). Although an α-level of 0.001 may have created a small number of type 1 errors, this was seen as an acceptable compromise. When data were normal, effect sizes were calculated using partial eta squared (η^2) with small, medium and large effects classified as values of 0.0099, 0.0588 and 0.1379 [36]. For non-normal data, Kendalls' W was used, with values of 0.1, 0.3 and 0.5 for small, medium and large effects, respectively [37].

Results

Descriptive characteristics of the participants are shown in Table 2. All participants who volunteered were eligible and completed the study. Figs. 1 and 2 show the normalised EMG values for all muscles. In all cases, there were significant differences between the 26 exercises, with medium to large effect sizes (mean EMG $146.6 < \chi^2 < 340.9$, $P < 0.001$; peak EMG $136.6 < \chi^2 < 334.1$, $P < 0.001$). Post-hoc Wilcoxon tests showed several differences between pairs of exercises for each muscle (presented in Matrix 1, see online supplementary material). Additionally, for each muscle, the exercises that were significantly different to the single exercise with the largest EMG are indicated by the shaded areas in Figs. 1 and 2.

The EMG data reveal some notable patterns regarding the exercises that produce higher activity for groups of muscles, as well as for exercises that consistently produce lower activity. Exercises 7, 8 and 10 seem to produce the highest muscle activity for the two gluteal muscles (GMax and GMed). Exercises 4 and 9 are among those producing the highest activity for the back muscles (ES and MF), with Exercises 6 and 17 producing the lowest activity. Exercise 12 for ES, and Exercises 7 and 8 for MF, also produced high muscle activity. For the abdominal muscles (RA, OE and OI), higher activity was recorded for Exercises 6, 12 and 17–19, while Exercises 13 and 16 consistently produced lower activity.

Fig. 3 shows pain, HR and RPE data. Significant post-hoc comparisons are shown in Matrix 2 (see online supplementary material), with Fig. 3 showing (with shading) the exercises that had significantly lower values than the exercise with the single highest value. There were only nine exercises with pain scores above zero (Exercises 1 L, 2, 3, 7 L, 7 R, 8 L, 8 R, 17 and 18), with pain being reported 15 times in total (occurrence 2.8%, mean intensity of non-zero scores 2.0). Seven participants reported pain in at least one exercise, with no obvious association between pain reporting and disability level of a participant (as indicated by the Oswestry Disability Index). Although the Friedman test showed a significant overall difference in

Table 1
Description of the aquatic exercises.

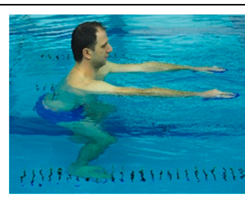
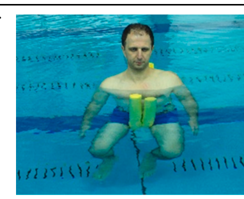
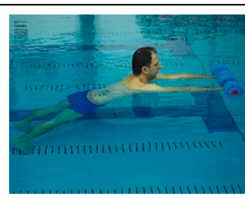
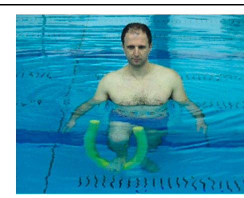
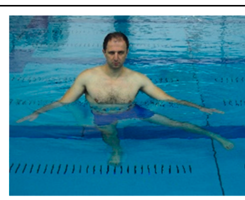
Description	Photo	Description	Photo
1 L and 1 R: Hold a plastic disc (23-cm diameter) between the hands just below water surface with arms fully outstretched in front. Rotate the trunk steadily as far to one side as possible and back to midline (35 bpm).		11: Hold dumbbell floats in each hand and position the arms by the side. Raise the knees alternately until thighs are parallel to the water surface (30 bpm).	
2: Hold a plastic board (34×24 cm) with arms fully outstretched just below water surface. Move the arms backwards towards the body and forwards to the starting position (45 bpm).		12: Float with dumbbells in each hand, arms extended down by the sides, and knees and hips flexed at 90°. Keep thighs parallel with a small gap between knees. Hold this position for 10 seconds, keeping as still as possible.	
3: Hold buoyant discs (12.5-cm diameter) in each hand just below water surface, the left arm close to the body and the right arm fully outstretched. Perform alternate reciprocal punching actions with the arms (30 bpm).		13 L and 13 R: Start in a lunge, with left leg forward and left knee slightly bent and above the toes. Arms out to the side, palms down, just under the surface. Lift left arm so that elbow is just clear of the water and hold for 5 seconds. Lower left arm and repeat with the right arm. Repeat five times. Then repeat with the right leg leading.	
4: Have arms by the sides (in forearm pronation) with plastic paddles (c.12.5×20 cm) strapped to the hands. Bring the arms together to just below water surface while flexing the knees to a squat. Return to the starting position (45 bpm).		14. Sit on a noodle with feet off the bottom of the pool. Have arms extended out to the side just under the water surface, palms down. Hold this position for 10 seconds, keeping as still as possible.	
5: Have the left arm by the side and the right arm outstretched in front, just below water surface, with forearms in supination and plastic paddles strapped to the hands. Bring left arm to just below water surface and simultaneously bring right arm to the side. Return to starting position (30 bpm).		15: Sit on a noodle with feet off the bottom of the pool. Have arms extended down by the sides. Hold this position for 10 seconds, keeping as still as possible.	
6: Have the trunk in an upright position, the arms outstretched and each hand holding a dumbbell float resting on the water surface. Move dumbbells forwards slowly with the body in a neutral posture tilting on the tips of the toes. Move back to starting position maintaining the neutral body position (12 bpm).		16 L and 16 R: Put a noodle under one foot and have the same side hip and knee bent at 90°. Keep arms by the sides. Push the noodle towards the bottom of the pool and bring it back to start position in a controlled manner. Keep the rest of the body as still as possible (25 bpm).	
7 L and 7 R: Stand on one leg with arms held in 45º abduction. Abduct the opposite leg as far as possible, retaining a neutral position throughout (avoid external rotation). Return to starting position (45 bpm).		17: Float on your back with two noodles supporting you under your shoulders and a person standing in the water behind you. Allow your head to relax back in the water. Keep two pool buoys between your knees. Bend your knees up towards your chest and straighten your legs back down to the starting position (40 bpm).	
8 L and 8 R: Stand on one leg with arms abducted at 45º. Perform hip extension maintaining the lower limb in a neutral position (avoid external hip rotation). Return to starting position (45 bpm).		18: From the same starting position as Exercise 17, bend knees up towards your chest and keep them flexed throughout the exercise. Move your knees side to side, allowing the lower trunk to rotate (45 bpm)	

Table 1 (*Continued*)

Description	Photo	Description	Photo
9 L and 9 R: Stand on one leg with arms crossed at chest, the non-weight bearing limb in a neutral position with the knee flexed to 90º. Perform single leg squat on the weight-bearing limb so that the knee moves just in front of the toes (50 bpm).		19: Float on your back with a noodle supporting you under your shoulders and hold on to the edge of the pool. Keep legs together and hold two pool buoys between your legs. Move the body from side to side, trying to keep hips straight, so that the movement happens from the upper trunk (35 bpm).	
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 (65 bpm).		20: Hold a kickboard (42×28 cm) on the water surface. Push the kickboard underwater until the arms are extended and bring it back to the water surface in a controlled manner (40 bpm).	

Notes: The above exercise list includes dynamic upper limb (1–6), dynamic lower limb (7–11), proprioception (12–15) and other (16–20) exercises. Exercises 1, 7, 8, 9, 13 and 16 were performed separately to the left and right. For Exercises 1–5 and 20, participants started with feet shoulder width apart and knees in slight flexion (between 15° and 30°). This lower limb position with a static pelvic posture was maintained throughout the exercises (except Exercise 4 where the static foot position alone was maintained). For Exercises 7–11, the participants were instructed not to move their trunk. Exercises 1–11 are as shown in Psycharakis et al. [20].

Table 2
Descriptive characteristics of the 20 participants (mean and standard deviation).

Age (years)	Height (m)	Body mass (kg)	Body mass index (kg/m^2)	Oswestry Disability Index (%)	TAMPA scale	STarT back total score	STarT back sub-score
33 (6)	1.8 (0.1)	83 (24)	24 (2)	21.1 (12)	32.5 (6)	1.5 (1.2)	0.7 (0.7)

pain between exercises (χ^2=40.44, P=0.026), there were no significant pairwise comparisons. Mean HR values ranged from 65 to 85 bpm, with individual values reaching 103 bpm. There were overall significant differences in HR between exercises ($F_{8.7,\ 165.6}$=9.69; $P<0.001$), with a large effect size (η^2=0.338). Post-hoc comparisons showed several pairwise differences involving all exercises except Exercises 6 and 11. The highest mean value for HR was observed for Exercise 6 (significantly higher than 11 other exercises), and the lowest mean value for HR was observed for Exercise 14 (significantly lower than eight other exercises). Mean RPE values ranged from 8.8 to 13.8, with individual values reaching 19. RPE also showed some significant differences between exercises (χ^2=117.6; $P<0.001$); Exercise 6 had significantly higher scores than 20 other exercises, while Exercises 7 and 8 (for both left and right movements) had significantly lower scores than other exercises.

Discussion

To the authors' knowledge, this is the first study to compare trunk and gluteal muscle activity between different aquatic exercises performed by people with CLBP. Rigorous methods were used to create a data set with 26 exercises and 14 muscles, which also includes information on pain, exertion and exercise intensity. This substantial evidence base can be used to inform prescription and progression of aquatic exercise programmes, and improve CLBP rehabilitation.

The EMG data revealed patterns that were similar for groups of muscles, and for both mean and peak muscle activity. Hence, it was deemed suitable to discuss such patterns collectively. First, for the two gluteal muscles, the highest activities were recorded during dynamic lower limb exercises of hip abduction/adduction and extension/flexion, which started from standing positions with knees extended (Exercises 7, 8 and 10). Thus, hip abduction/adduction and extension/flexion are recommended for programmes targeting gluteal muscles. These exercises were among those with the highest cadence (45–65 bpm) in the present study. As water resistance increases with speed of movement, the cadence of these exercises may have been a factor contributing to the higher gluteal muscle activity. In all three hip abduction/adduction and extension/flexion exercises, GMed had more than double the activity of GMax. Interestingly, for the hip abduction/adduction and extension/flexion exercises while standing on one leg (Exercises 7 and 8), GMed activity was similar for the supporting and moving legs. This may have important practical applications. For example, physiotherapists often use single-leg balance exercises at various angles of hip abduction or extension in order to activate GMed to prevent hip adduction or flexion, or control hip internal rotation. However, such exercises on land are often painful or too challenging for people with CLBP, and for those with fear or high risk of falling. Single-leg balance exercises could therefore be performed in water, where there is no risk of falling and the occurrence and intensity of pain are lower compared with similar exercises on land [20].

The other outcome variables for Exercises 7, 8 and 10 also revealed some interesting patterns. Exercise 8 (hip extension/flexion while standing on one leg) had the lowest RPE and among the lowest HR values, suggesting that high gluteal muscle activity can be produced even with exercises of low intensity and exertion. The hip adduction/abduction exercises (Exercises 7 and 10) also had among the lowest exertion scores, although the side steps of Exercise 10 seemed to increase intensity. There were four pain reports for Exercise 8 (10% occurrence), three for Exercise 7 (7.5% occurrence) and none for Exercise 10. Despite the pain reports for Exercises 7 and 8, pain intensity was very low (1.1 and 1.3, respectively, for the non-zero scores), and substantially lower than that of the same exercises performed on land (1.5 and 2.7, respectively [20]) and the 'generic' LBP intensity reported by participants at screening. Thus, both exercises are deemed appropriate for inclusion in rehabilitative programmes targeting gluteal muscles, while Exercise 10 could be the preferred option if pain in the former exercises is an issue. Strengthening of the gluteal muscles is important for people with CLBP, as gluteal muscle weakness is prevalent in this population and has been identified as a predictor for LBP [14]. Although data on the long-term effects of using hip abduction/adduction and flexion/extension in LBP aquatic rehabilitation programmes are lacking, similar exercises on land have been shown to increase the strength and activity of GMed following a 4-week intervention [38].

With decreased muscle endurance being linked to atrophy of paraspinal muscles such as MF, and with back extensor endurance identified as a risk factor for LBP [13], researchers have recommended targeting of ES and MF when exercising. Two squat exercises produced muscle activities among the highest recorded for ES and MF, and would be recommended for targeting those back muscles: squats with shoulder flexion (Exercise 4) and single-leg squats (Exercise 9). Exercise 4 had the highest intensity in the present study, while both Exercises 4 and 9 were pain free. Exercise 9 also produced relatively high activity for the gluteal muscles. The upwards and downwards movements in these two exercises mean that buoyancy has both an assistive and a resistive role for different parts of the exercises, which may have affected muscle activity and exercise intensity scores. Squat exercises have been reported to be effective in activating back extensor muscles on land. For example, for people with CLBP, Calatayud et al. [39] found that the two-leg squat produced the highest ES activity among eight trunk stability exercises. Marshall et al. [17] reported similar ES activity for a squat and a separate shoulder flexion exercise on land, which may suggest that the arm flexion in Exercise 4 is an important contributor to the increased ES activity. Some other exercises in the present study also showed high muscle activity for one of the back muscles. Exercise 12, a balancing proprioception exercise, produced high ES activity. The single-leg hip abduction/adduction (Exercise 7) and extension/flexion (Exercise 8) exercises showed high MF activity. At the other end of the spectrum, Exercises 6 and 17 consistently produced the lowest activities for the back muscles, and would only be recommended if the aims of an exercise programme were to keep back extensor activity low.

Abdominal muscle weakness has been reported frequently in people with CLBP [13,40], so strengthening the abdominal muscles should be prioritised in exercise rehabilitation. Evidently, exercises that make use of noodle/wall support and include leg movements while floating on the back (Exercises 17–19) are particularly effective for activation of the abdominal muscles. Exercise 19 had the second highest RPE and intensity scores, produced high activity in the oblique abdominal muscles, and was performed without any pain. Its trunk side flexion is likely more challenging and creates more resistance than exercises where fewer segments are moved and/or there is a smaller range of motion. Exercise 18 had higher pain occurrence and pain intensity than other exercises in the current study (15% and 2.8 for the non-zero scores, respectively), although the latter was because of a single high value (5.9) of one participant. Other exercises, such as a dynamic upper limb exercise (Exercise 6) and a static balance proprioception exercise (Exercise 12), also showed high abdominal muscle activity. Exercise 6, which has some similarities to plank exercises on land, is performed with a slow movement requiring increased trunk control. In addition to requiring increased abdominal activation, Exercise 6 had the highest perceived exertion among all exercises, while remaining pain free. In Exercise 12, it seems that increased abdominal engagement was required to hold the hips in the flexed position. Similar static balance proprioception exercises, such as Exercises 14 and 15, produced lower abdominal activity than Exercise 12. This was probably because by sitting on noodles in those exercises (instead of holding dumbbells in Exercise 12), there was less need for the abdominal muscles to help stabilise the position of the hips. This suggests that small changes in equipment or body position may cause meaningful changes in muscle activity, and such changes could be utilised in programme progression. It is also interesting to note that Exercises 6 and 17 consistently produced low activity for ES and MF, and can therefore engage the abdominal muscles substantially while

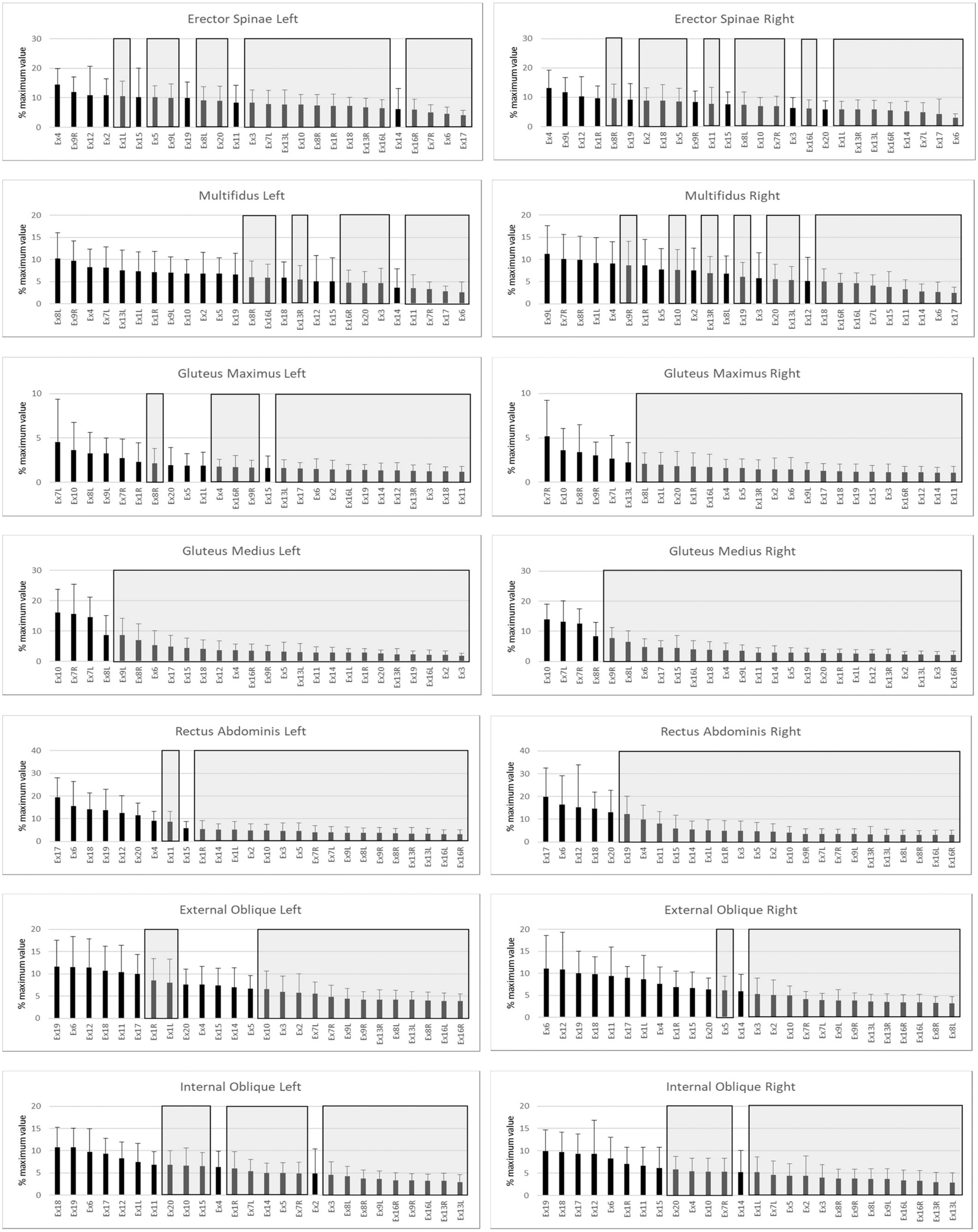


Fig. 1. Mean muscle activity for all muscles and exercises (mean group values and standard deviation). Muscle activity is calculated as a percentage of the maximum value of sub-maximal voluntary contractions obtained during separate exercises. The shaded areas indicate significantly lower activity than the single exercise with the highest activity for that muscle.

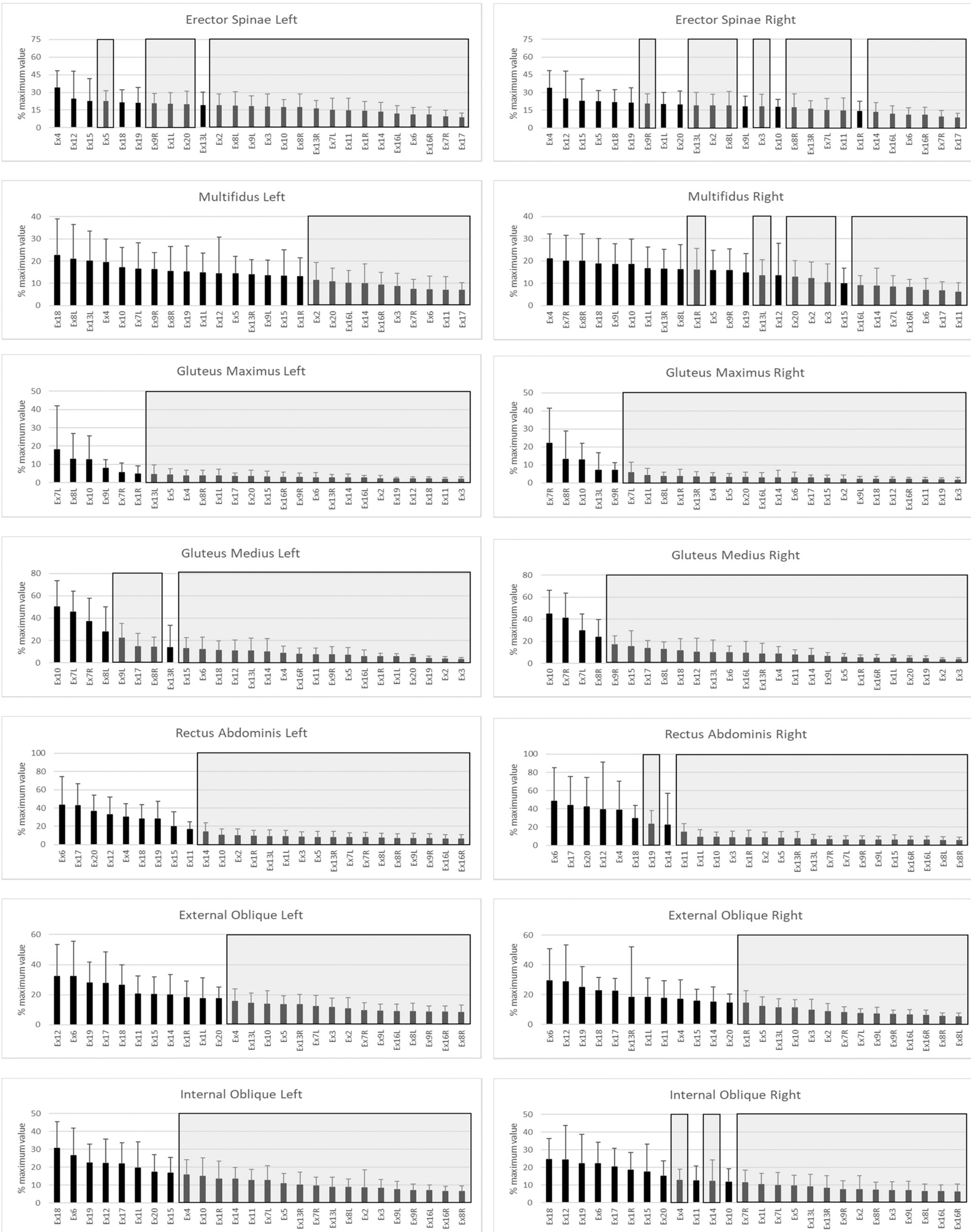


Fig. 2. Peak muscle activity for all muscles and exercises (mean group values and standard deviation). Muscle activity is calculated as a percentage of the maximum value of sub-maximal voluntary contractions obtained during separate exercises. The shaded areas indicate significantly lower activity than the single exercise with the highest activity for that muscle.

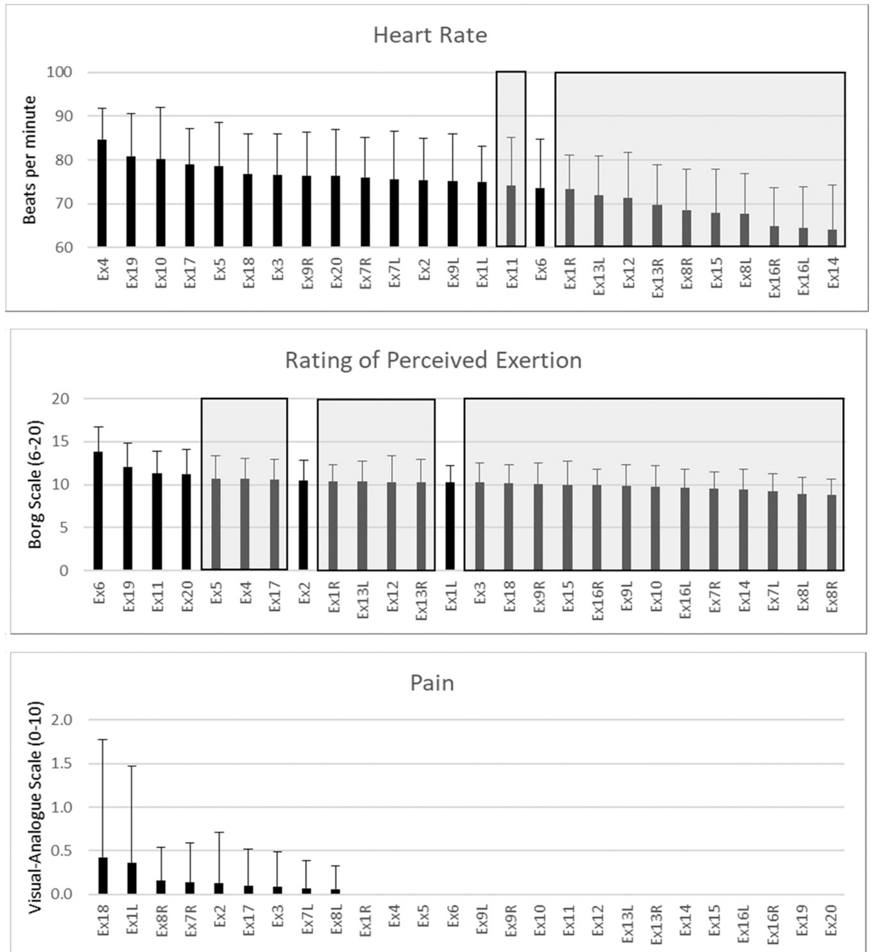


Fig. 3. Mean group values and standard deviation for heart rate, ratings of perceived exertion and pain. The shaded areas indicate significantly lower values than the single exercise with the highest values.

keeping back extensor activity at low levels. Finally, Exercises 13 and 16 are recommended when abdominal muscle activity needs to remain low.

This study had a few limitations. First, all exercises had specific cadence and resistance. Future research could explore the effects of altering resistance on all outcome measures. Second, the participants were 18–45-year-old males with BMI < 28 kg/m^2 and mild-to-moderate disability. Subsequent studies should include both genders, increase the age and BMI ranges, and include different levels of disability and LBP classification.

Conclusion

This study explored 26 rehabilitative aquatic exercises performed by people with CLBP. Pain occurrence and intensity were very low, with the majority of exercises being completely pain free, which is often of vital importance when deciding on the exercise environment (e.g. water or land) for people with CLBP. When the aim of a programme is to target specific muscle groups, hip abduction/adduction and extension/flexion exercises are particularly effective in increasing muscle activity for the gluteal muscles and, often, MF. Variations of squat exercises, with or without shoulder flexion, increase activity of the back extensors, while exercises that make use of support buoyancy equipment and include leg movements while floating on the back increase abdominal muscle activity. This list is not exhaustive as some other exercises also produce high muscle activity for particular muscles or groups. Moreover, programme design needs to include progression and variation in exercise type and in magnitude of muscle activity. Thus, physiotherapists can use the information on all 26 exercises to inform programme prescription by selecting and alternating rehabilitative exercises, implementing programme progression, and tailoring the programme to suit individual needs.

Ethical approval: Ethical approval was obtained from the Ethics Committee of the Moray House School of Education and Sport (University of Edinburgh).

Funding: This work was funded by the Chief Scientist Office in Scotland (Ref. No. ETM/378). The funder played no role in the design, conduct or reporting of this study.

Conflict of interest: None declared.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.physio.2022.03.003.

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