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Phasic-to-tonic shift in trunk muscle activity relative to walking during low-impact weight bearing exercise

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ABSTRACT

The aim of this study was to investigate the influence of an exercise device, designed to improve the function of lumbopelvic muscles via low-impact weight-bearing exercise, on electromyographic (EMG) activity of lumbopelvic, including abdominal muscles. Surface EMG activity was collected from lumbar multifidus (LM), erector spinae (ES), internal oblique (IO), external oblique (EO) and rectus abdominis (RA) during overground walking (OW) and exercise device (EX) conditions. During walking, most muscles showed peaks in activity which were not seen during EX. Spinal extensors (LM, ES) were more active in EX. Internal oblique and RA were less active in EX. In EX, LM and ES were active for longer than during OW. Conversely, EO and RA were active for a shorter duration in EX than OW. The exercise device showed a phasic-to-tonic shift in activation of both local and global lumbopelvic muscles and promoted increased activation of spinal extensors in relation to walking. These features could make the exercise device a useful rehabilitative tool for populations with lumbopelvic muscle atrophy and dysfunction, including those recovering from deconditioning due to long-term bed rest and microgravity in astronauts.

1. Introduction

in vivo spinal loadings can range from 6 kN whilst performing typical everyday tasks [1] to more than 36 kN during intense physical activities [2,3]. The lumbopelvic musculature makes a significant contribution to the maintenance of trunk stability against these loads [3,4]. Specifically, the local muscles of the lumbopelvic region, such as lumbar multifidus (LM) and transversus abdominis (TrA), play a vital role in the maintenance of lumbar spine [5,6] and sacro-iliac joint [7] inter-segmental stability. When working optimally, local muscles are activated at much lower levels than global muscles, and local muscles work in a much more tonic fashion [8], as well as in anticipation of loads or movement, rather than in response to them [5]. If local muscles become dysfunctional, global muscles try to compensate. However, the action of global muscles exerts considerable loads on the spine which result in shearing strains at inter-vertebral level, unless the local muscles work effectively to achieve inter-segmental stability [4]. Table 1 summarises the key differences between local and global muscles [5,8,9].

In people with low back pain (LBP), the local lumbopelvic muscles, i.e. the muscles that are responsible for inter-segmental stability, are known to be atrophied [10,11] and show altered motor control [5]. Exposure to microgravity and long-term bed rest (LTBR), an analogue to exposure to micro-gravity, too, are known to lead to atrophy and dysfunction of the local spinal muscles [12–14], and it has been suggested that this dysfunction is likely to be a major contributing factor to the increased

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Table 1
Key characteristics of global and local muscles [5,8,9].

	Global (mobilising) muscles	Local (stabilising) muscles
Action	Produce movement Work in response to loads Work phasically	Prevent or decelerate movement Work in anticipation of loads (incl. loads generated by movement of body segments and/or limbs) Work tonically
Physiology	Fatigue quickly and need breaks between contractions Fast-twitch (type II) fibres Low excitation threshold Work at 40–100% Maximum voluntary contraction (MVC) Powerful; able to generate great force Atrophy moderately on exposure to micro-gravity/LTBR	Do not fatigue and do not require rest periods Slow-twitch (type I) fibres High excitation threshold Work at up to 30% MVC Much weaker; able to generate only moderate force Atrophy severely on exposure to micro-gravity/LTBR
Structure	Superficial/away from joint axes to create maximum leverage Long Usually cross two or more joints Long tendons to direct force	Deep/close to joint axes to prevent shearing forces/strains Short, often flat and wide Usually cross only one joint Wide aponeuroses to dissipate force

risk of back injury in astronauts immediately post space flight [12,15]. In fact, Johnson et al. [15] have reported a more than four-fold incidence of disc herniation in U.S. astronauts post mission as compared to their non-astronaut peers. As little as 14 days of LTBR has been shown to lead to significant local lumbopelvic muscle atrophy [16]. Long term bed rest has also been shown to lead to selective atrophy of the spinal extensors, and hypertrophy of the spinal flexors [13], a pattern also recognised in astronauts [17], as well as to a tonic-to-phasic shift in local lumbopelvic muscle recruitment [16].

Segmental spinal stabilisation exercises including the “abdominal drawing in manoeuvre” [18,19], and Specific Motor Control Training [20], general strength training [20,21], vibration exercise [22], and resistive exercise with whole body vibration [23] have all been used as countermeasures for deconditioning during LTBR [21–23], or as rehabilitative interventions with astronauts [24] and/or post LTBR populations [20]. However, there is little evidence on the use and rigorous testing of rehabilitation interventions specifically following LTBR [20] and/or post space flight. Importantly, Belavý et al. [12] have demonstrated that the lumbar multifidus muscle does not recover its pre-LTBR function even after six months post LTBR. In other words, lumbopelvic inter-segmental stability is likely to remain compromised in the long term with current approaches.

In recent years there has been a drive to make rehabilitative interventions for people with LBP more functional [25,26], and whilst some exercise approaches have been shown to recruit LM and/or TrA, many are limited in their functional relevance to activities of daily living, such as walking and maintaining an upright posture against gravity. Most of these interventions also require conscious voluntary contraction from the participant to activate the local muscles which is known to be difficult [27]. As arguably the most functionally relevant activity to most people, walking has been suggested as a potential therapeutic intervention for LBP [28,29]. However, conflicting evidence has been presented in the literature, and a recent meta-analysis suggested that walking is not effective in this context [30]. For a functionally relevant intervention to be developed, however, it should consider the key elements of walking. In its simplest terms, walking consists of a relatively stable upper body positioned on top of a moving base of support.

Fig. 1. The Functional Re-adaptive Exercise Device (FRED) (from Debuse et al. [31], with permission). The feet are constrained to move in a quasi-elliptical path. The device can be used in either sitting or standing.

A Functional Re-adaptive Exercise Device (or FRED) has been developed that results in low-impact weight-bearing exercise and has been designed specifically to improve the function of the local lumbo-pelvic and lower limb

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anti-gravity muscles (see Fig. 1). The absence of external resistance to foot motion, and therefore, an unstable base of support, places a much greater demand on balance, coordination and motor control than conventional exercise devices. As a result, the local lumbo-pelvic muscles are recruited during FRED exercise to stabilise the spine during exercise [31]. The primary aim of FRED exercise is not to strengthen muscles, but to improve users' motor control.

Debuse et al. [31] demonstrated that exercising on the device recruited both LM and TrA automatically, i.e. without a conscious/voluntary contraction. The exercise device was also compared to overground walking using three dimensional motion analysis and was shown to achieve a more stable lumbopelvic region, through reduced axial rotation of the spine, and to increase anterior pelvic tilt [32]. This more stable lumbopelvic region could be indicative of more tonic muscle activity which has been shown previously to be a key characteristic for training local muscles [8]. However, the influence of the exercise device on lumbopelvic muscle activity throughout a complete foot movement cycle, or in comparison to walking, has not yet been determined.

The aims of this investigation were to determine (1) lumbopelvic muscle recruitment over a complete foot movement cycle, and (2) differences in lumbopelvic muscle activity between overground walking and when using the exercise device.

2. Methods

2.1. Participants

Fifteen male participants took part in this study. They had a mean (±SD) age, height and mass of 24.93 (±3.92) years, 1.78 (±0.05) m, and 83.03 (±7.21) kg, respectively. All participants were free from injury and non-symptomatic at the time of the study. The study was approved by the Institutional Review Board and all participants gave written informed consent to take part. The surface EMG data were collected during the same study as the kinematic data presented by Gibbon et al. [32].

2.2. Protocol

Participants attended a single session, during which they completed trials in both overground walking (OW) and exercise device (EX) conditions. The order of conditions was randomised to avoid any systematic effects on the data. For OW, participants were asked to walk at their preferred speed along a walkway. Sufficient trials were completed to ensure that six successful trials were available for analysis. A trial was considered successful when participants landed with their right foot striking the first of two force platforms without evidence of targeting.

In EX, participants were given a five minute period to familiarise themselves with the exercise device. They were instructed to keep their feet in contact with the foot plates at all times, and to move their feet at their preferred speed, ensuring that foot movement was slow and controlled. Participants were instructed to keep their upper body as still as possible and to remain in an upright posture throughout. Each participant completed a single 30 s EX trial in order to obtain six complete movement cycles. A movement cycle was defined as the feet completing a whole revolution of the movement cycle starting and ending with their right foot at the furthest point forward.

2.3. Equipment

For OW trials, identification of heel strike and toe off events was aided by two force platforms (OR6–7, AMTI, Watertown) within the walkway in the centre of the laboratory. Signals were amplified (gain = 1000, MSA-6, AMTI, Watertown), and sampled at 2000 Hz by a data acquisition card (MX, Vicon Motion Systems, Oxford).

For EX trials, 3D trajectories of retro-reflective markers (⌀ = 14 mm) placed on the side of the right foot plate were tracked and sampled at 200 Hz using a 12 camera motion capture system (MX T20, Vicon Motion Systems, Oxford, UK) to aid the demarcation of key cycle events. The start and end of each movement cycle were determined by the most anterior and posterior positions of these markers. Rearward movement of the foot plate (i.e. when the foot moved backwards under the body) was considered comparable to the stance phase of the walking gait cycle, whereas forward movement of the foot plate (i.e. when the foot moved forwards under the body) was considered comparable to the swing phase of the walking gait cycle.

Surface EMG data were collected using surface electrodes from lumbar multifidus (LM), erector spinae (ES), internal oblique (IO), external oblique (EO) and lower rectus abdominis (RA), placed unilaterally on the right side of the body. Electrode sites were shaved to remove body hair, rubbed using abrasive gel, and cleaned with alcohol swabs. Pre-gelled self-adhesive circular electrodes (Ag/AgCl, diameter = 34 mm, sensing area = 13.2 mm^2, measurement area = 154 mm^2, Blue Sensor S, Ambu, Ballerup, Denmark) were placed in a bipolar configuration in accordance with existing protocols [33,34] with an inter-electrode distance of 20 mm. Although potential for cross talk exists in each EMG signal, previous investigations using the same electrode placement have shown this to be insignificant for the anterior abdominal muscles [3,35–37] and between the spinal extensors [35].

Raw signals from each muscle were pre-amplified (gain = 1000, common mode rejection ratio $>$100 dB) and passed telemetrically to a data receiver (Myon RFTD-E16, Myon AG, Baar, Switzerland) before being amplified and sampled at 2000 Hz by a data acquisition card (MX, Vicon Motion Systems, Oxford, UK). All data were collected simultaneously and stored in specialist software (Nexus 1.7, Vicon Motion Systems, Oxford) for subsequent analysis.

2.4. Data analysis

Myoelectric data for each muscle were processed within Nexus (1.7, Vicon Motion Systems, Oxford), using an EMG plugin (ProEMG, Pro Physics AG, Zurich). All channels were band-pass filtered (Butterworth 2nd order, 10–350 Hz), smoothed using root mean square (RMS) with a moving window width of 40 ms [32] and time

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normalised to one complete right gait/movement cycle. All signals for both OW and EX gait cycles were then amplitude normalised to the peak RMS EMG amplitude from the OW trials for each muscle [38]. Time and amplitude normalised RMS EMG signals for each muscle for each participant were then ensemble averaged for either OW (six gait cycles for the right leg) or EX (six right leg movement cycles). Mean EMG was calculated from the amplitude and time normalised RMS EMG curves for each muscle.

Baseline EMG for each muscle, collected during a 30 s trial where the participant was supine and all muscles were relaxed, was filtered as described above for OW and EX trials, before being full-wave rectified. The mean and standard deviation (SD) of the rectified baseline EMG for each muscle were determined. The timing of muscle activity onset and cessation was then determined by the points at which the RMS EMG signals raised above or dropped below the mean plus two SDs of the baseline rectified signal, respectively [39]. The proportion of the gait cycle that each muscle was active in OW and EX was subsequently determined.

Data for mean RMS EMG and the proportion of the gait cycle that each muscle was active were checked for normality using *Q*–*Q* and box plots. For variables that were normally distributed, mean EMG and time active data were compared between OW and EX using paired samples *t* tests. For data that were not normally distributed, OW and EX were compared using Wilcoxon signed rank tests. Confidence intervals (95%) were also determined for each variable for each muscle between OW and EX. A 95% significance level was used throughout.

3. Results

The majority of data were normally distributed, with the exception of mean RMS EMG in LM and ES, and the proportion of the gait/movement cycle the muscle was active in IO and RA. In OW, LM showed phasic patterns of activity with peaks in activity around the start and mid-way through the gait cycle (Fig. 2). In EX, however, a tonic pattern of activity was seen. Mean LM activity (Table 2) in EX was significantly greater than in OW ($Z=3.067$, $p<0.01$), as was the proportion of the gait/movement cycle for which LM was active ($t(13)=6.618$, $p<0.001$) (Table 3).

Like LM, ES showed peaks of muscle activity at the start and around half way through the gait/movement cycle in OW (Fig. 2). In EX, ES muscle activity was lowest at the start and end of the gait cycle, increasing gradually towards maximum activity around half way through the gait/movement cycle. Unlike OW, no discernible peaks in activity were observed for ES during EX trials. Mean ES activity (Table 2) was significantly greater in EX compared to OW ($Z=3.067$, $p=0.002$), and ES was active for a significantly greater proportion of the gait cycle during EX ($t(13)=3.313$, $p=0.005$) (Table 3).

Similar to LM and ES, IO showed a change from phasic activity during OW to tonic activity during EX (Fig. 3). The mean level of activity in the IO was significantly lower in EX than in OW ($t(13)=4.694$, $p<0.001$) (Table 2) although both conditions showed IO activity above baseline levels for the majority of the gait cycle, with no difference seen between conditions ($Z=0.764$, $p=0.445$) (Table 3).

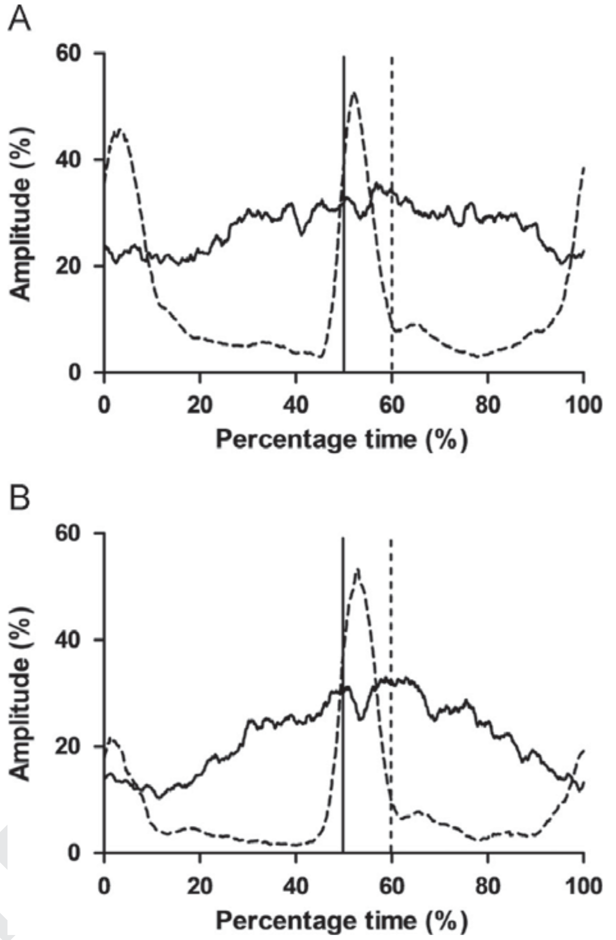

Fig. 2. Normalised RMS EMG shown for (A) lumbar multifidus and (B) erector spinae in walking (- -) and exercise device (—) conditions, over one gait cycle. Heel strike in overground walking and the most anterior position of the foot plate in the exercise device condition occurred at 0% and 100% of the movement cycle. Vertical lines indicate toe off in overground walking (- -) and the most posterior position of the foot plate in the exercise device condition (—) conditions.

During OW, peaks in EO activity were seen at, and just prior to, half way through and towards the end of the gait/movement cycle (Fig. 3), although these peaks were not as prominent as those seen in LM and ES (Fig. 2). In EX, more tonic activity was observed in EO than in OW. Mean EO activity was similar between OW and EX ($t(13)=1.931$, $p=0.074$) (Table 2), although it was active for a significantly reduced proportion of the gait cycle in EX ($t(13)=2.741$, $p=0.016$) (Table 3).

Walking resulted in three slight peaks in RA activity at the start, just before half way through, and towards the end of the gait cycle (Fig. 3). During EX, a more tonic pattern of RA activity was observed with no discernible peaks in activity. Mean RA EMG activity was significantly reduced in EX compared to OW ($t(13)=4.164$, $p=0.001$) (Table 2). Despite the apparent tonic activation of RA in EX, the level of activity only rose above the threshold defined for muscle activation, and thus active, for a significantly

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Table 2
Q5 Mean RMS EMG amplitude over one gait cycle.

Muscle	Walking		Exercise device		Mean difference†	95% Confidence interval		p
	Mean	*SD*	Mean	*SD*		Lower	Upper	
LM	13.5	*3.98*	27.38	*15.61*	13.87	4.922	22.82	0.005*
ES	9.42	*4.13*	21.70	*17.92*	12.27	1.84	22.70	0.024*
IO	19.96	*4.45*	14.62	*4.82*	−5.35	−7.79	−2.90	< 0.001*
EO	17.42	*8.67*	13.55	*8.11*	−3.87	−8.16	0.43	0.074
RA	15.06	*3.82*	8.67	*5.62*	−6.34	−9.69	−3.10	0.001*

LM = lumbar multifidus, IO = internal oblique, ES = erector spinae, EO = external oblique, and RA = rectus abdominis.
† Positive mean difference indicates increase in exercise device condition compared to walking.
* Significant at $p < 0.05$ level.

Table 3
Percentage of gait/movement cycle that each muscle is active.

Muscle	Walking		Exercise device		Mean difference†	95% Confidence interval		p
	Mean	*SD*	Mean	*SD*		Lower	Upper	
LM	33.42	*21.61*	78.52	*30.52*	45.10	30.48	59.72	< 0.001*
ES	17.69	*12.44*	49.56	*41.94*	31.87	11.24	52.50	0.005*
IO	79.52	*28.93*	79.57	*35.34*	0.05	−7.54	7.65	0.988
EO	33.93	*35.66*	8.51	*12.88*	−25.42	−45.32	−5.53	0.016*
RA	18.16	*23.61*	0.00	*0.00*	−18.16	−31.79	−4.54	0.013*

LM = lumbar multifidus, IO = internal oblique, ES = erector spinae, EO = external oblique, and RA = rectus abdominis.
† Positive mean difference indicates increase in exercise device condition compared to walking;
* Significant at $p < 0.05$ level.

reduced proportion of the movement cycle compared to OW ($Z = 2.803$, $p = 0.005$) (Table 3).

4. Discussion

The aims of this study were to identify how lumbopelvic muscles are recruited through a complete movement cycle when using the Functional Readaptive Exercise Device (FRED) designed to target the muscles of the lumbopelvic region, and to determine how the muscle activity compares to that seen during overground walking. The key findings of the study were that exercising with FRED (a) promoted tonic activity of the lumbopelvic musculature, as compared to OW which resulted in phasic activity of the lumbopelvic muscles, and (b) resulted in greater spinal extensor activity than spinal flexor muscles as compared with OW.

4.1. Phasic-to-tonic shift in muscle activity relative to walking

During OW, all muscles showed one or more distinct peaks in activity. For most muscles, these peaks occurred around the start of (heel strike), and midway through the gait cycle (just prior to toe off). This is consistent with previous research that observed peaks in lumbopelvic muscle activity around heel strike and toe off in walking [40]. Saunders et al. [40] observed phasic activity of LM (superficial and deep fibres), ES, IO and EO, where bursts of activity were associated with the need to maintain lumbopelvic stability at heel strike and toe off [41], and the need to absorb impact forces at heel strike [42].

Internal oblique in the present study was active for the majority of the gait cycle during OW, but showed biphasic modulation which has been linked to respiration and changes in trunk motion through the gait cycle [40]. During EX, these peaks in activity were not apparent, suggesting a shift from phasic to tonic activity. Despite this shift from phasic to tonic activation of IO, the duration of IO activity was not different between OW and EX, being active for the majority of the gait cycle. Saunders et al. [40] also observed tonic activity in IO during walking with multiple bursts of increased activity throughout the gait cycle, supporting our observations during OW. Our findings demonstrate that despite tonic IO activity being seen in OW, a more constant level of tonic activation was observed during EX, which would facilitate the local motor units within the muscle [8]. Analysis of kinematic data collected during the same study [32] showed reduced axial rotation of the lumbopelvic region during EX compared to OW. This was likely caused, in part, by the more tonic activity of IO observed here, as IO is known to have a primary action in axial spinal rotation [43,44].

Lumbar multifidus and ES muscles were active for a significantly longer proportion of the gait/movement cycle in EX compared to OW. Previously it has been shown that exercise on FRED causes an anterior pelvic tilt compared to walking [32]. Similar magnitudes of anterior tilt [45] have

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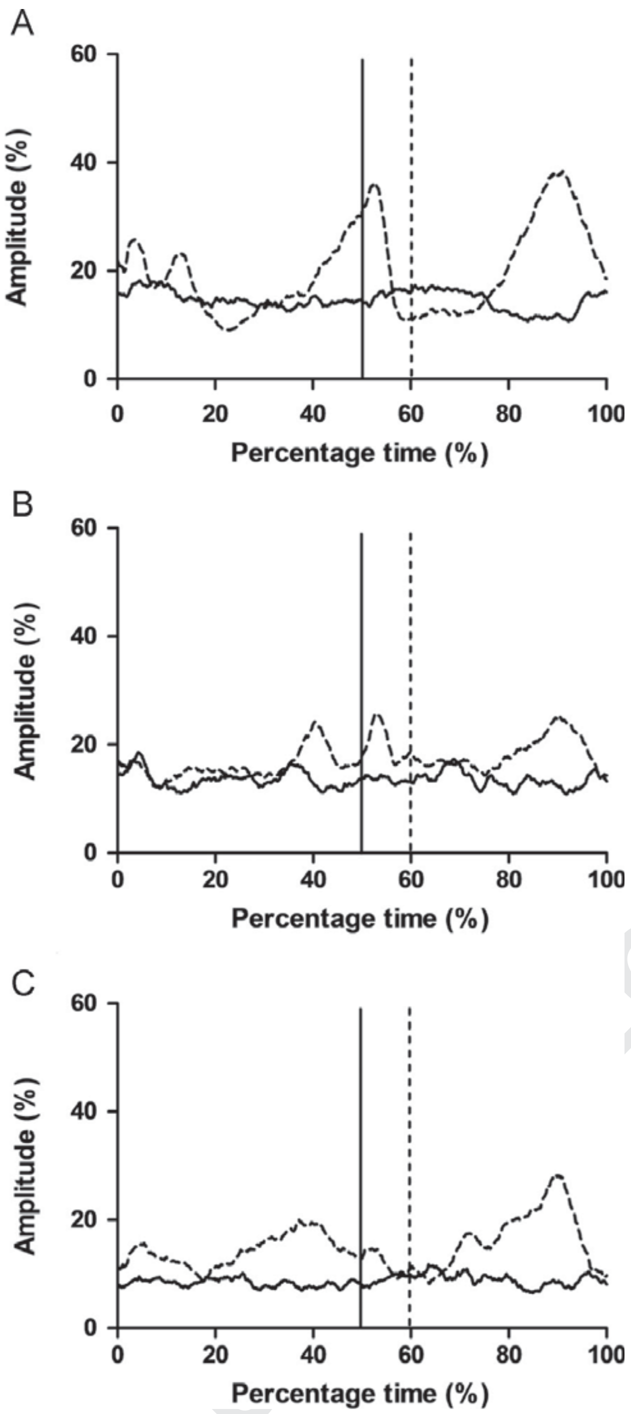

Fig. 3. Normalised RMS EMG shown for (A) internal oblique, (B) external oblique and (C) rectus abdominis in walking (- -) and exercise device (—) conditions, over one gait cycle. Heel strike in overground walking and the most anterior position of the foot plate in the exercise device condition occurred at 0% and 100% of the movement cycle. Vertical lines indicate toe off in overground walking (- -) and the most posterior position of the foot plate in the exercise device condition (—) conditions.

been shown to recruit the deep and superficial fibres of LM to the levels required for optimal local muscle recruitment (20–30% maximal voluntary contraction) [46]. The findings presented here appear to support the notion that exercising on FRED promotes optimal activation of LM for the promotion of lumbopelvic stability. The more tonic nature of ES activity in EX throughout the movement cycle may suggest a favourable recruitment of these muscles during exercise on FRED compared with overground walking.

The finding that FRED exercise leads to phasic-to-tonic shift in lumbo-pelvic muscle activity compared with walking is highly relevant to astronauts and people recovering from LTBR. Belavy et al. [16] demonstrated that eight weeks of bed rest resulted in a tonic-to-phasic shift of lumbar ES activity during a knee flexion–extension activity. This tonic-to-phasic shift in muscle recruitment patterns persisted over the six month follow-up period after the end of the bed rest trial and, in fact, was more exaggerated once participants returned to an upright posture. The lack of recovery of tonic firing of the spinal extensors six months following a period of bed rest [16] suggests that the nature of muscle recruitment does not recover to its pre-bedrest state without therapeutic intervention. Similarly, Hodges and Moseley [47] showed a link between LBP and reduced tonic activity in the local lumbopelvic muscles. Exercise with FRED would seem to produce exactly the opposite effect to LTBR and exposure to micro-gravity and may lead to improvements in lumbopelvic stability. Further research is needed to determine the effectiveness of FRED exercise in the rehabilitation of clinical populations.

Walking has previously been proposed as a therapeutic intervention for LBP [28]. However, there is a lack of consensus about the efficacy of walking in reducing LBP [30]. The data presented here and in previous literature [40] suggest that the lack of improvement in LBP seen when using walking therapeutically could be due to the mainly biphasic activity of the lumbopelvic muscles. For optimal lumbopelvic stability, the local muscles of the lumbopelvic region are required to work tonically [8]. The promotion of tonic activation seen during FRED exercise is likely to make the exercise device more effective for rehabilitation following LBP, LTBR and long-term space flight than walking.

4.2. *Promotion of spinal extensor muscle activity*

Mean levels of muscle activity over one gait cycle were significantly increased in LM and ES in EX compared to OW. Conversely, mean activity in RA and IO was significantly reduced in EX compared to OW. Previous studies investigating the influence of pelvic tilt on LM activity [45] showed that LM is much more likely to be recruited in a position of anterior pelvic tilt (relative to neutral). This means that the level of anterior tilt seen when using the exercise device [32] could be optimal for recruitment of LM. This, too, is of great relevance to people recovering from LTBR and astronauts. Buckey [17] describes that the posture of astronauts is characterised by increased trunk and limb flexion and points to a selective atrophy of the spinal extensors. The same effect is seen following LTBR. Hides et al. [13] investigated the influence of LTBR on lumbopelvic muscle size using magnetic resonance imaging, and found selective atrophy of the spinal extensor muscles, in particular LM. In fact, the reduction in LM cross sectional area seen after LTBR is similar to its response to LBP [48,49]. The spinal flexor muscles including psoas,

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external oblique and rectus abdominis, however, were found to increase their cross sectional area following LTBR [13]. The subsequent imbalance between flexor and extensor size and function could impact upon the ability of the lumbopelvic muscles to maintain spinal stability, which is likely to contribute to an increased risk of low back pain following LTBR [16]. What is likely to compound the problem further is that LM is not only atrophied following LTBR and long-term space flight [24], it is also in a stretched position [23] which inhibits it from being recruited at all [9]. The fact that exercise on FRED results in a lumbo-pelvic position that is particularly favourable to effective LM recruitment and activity [45] in non-symptomatic volunteers, may offer an advantage in this respect.

In an attempt to address the clear need to prevent the spinal extensor muscle atrophy seen in LTBR, Belavý et al. [23] investigated the use of a combined vibration and resistive exercise countermeasure. Changes in lumbopelvic muscle cross sectional area were assessed during 8 weeks of LTBR and for six months following return to an upright posture. Significant atrophy of LM was observed which was reduced, but not eradicated, through the use of resistive vibration exercise. Importantly, ES had recovered and, in fact, improved on, its pre-LTBR state by 28 days following the end of LTBR, while LM did not recover its pre-LTBR cross sectional area even after six months [23]. This points to very different rehabilitation requirements between the two muscles which have not been addressed adequately in the literature to date.

The extensor–flexor imbalance of the lumbopelvic musculature reported in both people following LTBR, and people with LBP highlights the need for a rehabilitative tool that is able to address the atrophy of the spinal extensors in order to counteract any increase in the size of the spinal flexors. Currently, most therapeutic interventions evaluated during LTBR and LBP studies lack functional relevance to activities of daily living. Also, to date, muscle cross sectional area and/or thickness determined by ultrasound imaging (e.g. [10,11]) or MRI (e.g. [10,18]) has been studied, but not the type of muscle activity (i.e. tonic or phasic), or whether the local lumbo-pelvic muscles have regained their anticipatory action.

4.3. *Greater increase in LM than ES activity during EX compared to OW*

Q2 Our findings also show that the mean difference between EX and OW for LM was slightly greater for RMS EMG amplitude compared to ES (13.87% vs. 12.27%, respectively), and was notably greater for LM compared to ES for the percentage of movement cycle the muscle was active (45.10% vs. 31.87%, respectively). While it was not possible to investigate Transversus Abdominis (TrA) activity using surface EMG, Debuse et al. [31] previously showed significantly greater TrA activity during FRED exercise than during a range of control conditions. Together with the findings for LM in this study, this may indicate that exercise on FRED results in greater recruitment of local than global lumbo-pelvic muscles, in general. Local muscles are responsible for segmental spinal stability [4–7], and the fact that there is greater atrophy of the local than global muscles following LTBR and exposure to micro-gravity [12–14] has been suggested as a reason for the four-fold incidence in disc prolapse in astronauts as compared to their peers. Particularly if a similar pattern of activation during FRED exercise was to be found for TrA, this could point to FRED exercise being more effective at addressing local muscle atrophy in people with LBP, following LTBR, and astronauts than conventional exercise approaches.

4.4. *Limitations*

In populations with LBP, following LTBR and following exposure to micro-gravity, the local lumbopelvic muscles are atrophied and dysfunctional. Transversus abdominis and lumbar multifidus are the most widely studied, and likely the most important muscles in this context. However, as TrA is situated deep within the anterolateral abdominal wall, it cannot be studied with surface EMG, and its activity could, therefore, not be examined in this study.

Despite previous reports of insignificant electrical cross talk affecting the EMG signals measured here [3,35–37], there is still the possibility that the signals could have been influenced by some cross talk. Research using indwelling EMG electrodes is warranted in order to fully validate the findings presented here, as well as to identify the contribution TrA makes to the maintenance of spinal stability when using the Functional Readaptive Exercise Device.

5. Conclusion

This study has demonstrated that using the Functional Readaptive Exercise Device (FRED) leads to more tonic activation of lumbopelvic muscles, in general, compared to walking. In addition, levels of muscle activity during exercise on FRED were increased in the spinal extensor muscles and were reduced in the spinal flexors. The fact that immediate exposure to FRED exercise results in a phasic-to-tonic shift in overall muscle activation when compared to overground walking and in a preferential activation of spinal extensors over the spinal flexors, as compared to overground walking suggests that the new FRED exercise device could be a highly effective tool for use in rehabilitation of people following LTBR, in those with LBP and potentially in astronauts returning from long-term space missions. Further research is needed to evaluate the effectiveness of FRED exercise in restoring the extensor–flexor imbalance of the lumbo-pelvic musculature in these populations.

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