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Original research

The influence of ‘Slacklining’ on quadriceps rehabilitation, activation and intensity

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ABSTRACT

Objectives: To determine and compare the level of quadriceps activation for knee injured participants during kinetic open-chain, closed-chain and composite-chain (Slackline) clinical exercises. Quadriceps activation is a critical component of lower limb movement and subsequently, rehabilitation. However, selective activation can be difficult due to pain, loss of function and impaired neuro-motor activation.

Design: Repeated measures (within-subjects) ANOVA.

Methods: Consecutive physiotherapy outpatients ($n=49$, 41.8 ± 16.8 years, range 13–72 years, 57% female) with an acute (<2 weeks) knee injury were recruited. Participants were assessed for quadriceps activation using skin mounted electromyography during five separate clinical quadriceps activation exercises: two open-chain, inner range quads and straight leg raise; two closed-chain, step down and step up; and a composite-chain, slacklining step-up. Outcome measures were: median score on electromyography as measured in microvolts (μV); and perceived exertion on an 11-point numerical rating scale.

Results: Median scores of the open- and closed-chain exercises showed no statistical difference, while composite-chain Slackline exercise showed significantly ($p < 0.0001$) higher quadriceps activation ($F_{(2,52, 121.00)} = 21.53$, $p < 0.0001$) at significantly lower exertion ($F_{(1,62, 77.70)} = 26.88$, $p < 0.0001$).

Conclusions: The use of Slackline rehabilitation training can provide significant increases in activation and recruitment of the quadriceps for composite-chain exercises in the clinical setting. This activation occurs spontaneously at significantly lower levels of perceived exertion. This spontaneous quadriceps activation in a selective and simple manner is a valuable adjunct exercise for lower limb rehabilitation programmes. This is of particular relevance for the outpatient setting and circumstances where the quadriceps is inhibited and activation is required.

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1. Introduction

Activation of the quadriceps muscle is a critical aspect of knee and lower limb function and when required, the rehabilitation process. It is recognised that following injury or surgery to the lower limb, incomplete voluntary activation of the quadriceps leads to weakness and subsequent secondary problems¹ in both the affected and unaffected limb.² These problems can include loss of function,³ failure to return to sport⁴ and premature onset of osteoarthritis.⁵ The presence of increased pain⁶ can cause up to a 34% decrease in maximal isometric knee extension torque.⁷ However, the use of weight-bearing (WB) or non-weight-bearing (NWB) knee-extension exercises does not acutely change quadriceps torque output or the levels of activation.⁸ Selective muscle

activation can also be difficult due to pain inhibition, loss of function and impaired neuro-motor activation. Consequently, the required voluntary activation has been found to correlate highly with knee extension force production.⁹ This can occur through open, closed, and composite-kinetic chain exercises. Composite-chain activity occurs when there is a weak link in the kinetic chain that creates abnormal motor synergy patterns.¹⁰ Composite-chain activity is present when the loaded limb's contact surface is able to move freely, such as in three dimensions. Consequently it is critical for individuals with a knee injury to initiate early quadriceps activation¹¹ and preferably with minimal perceived voluntary activation.

The use of active exercises is one of the simplest and most efficient techniques to achieve active selective quadriceps activation.^{12,13} It would be even more advantageous if these exercises were easy to perform, enabled a rapid gaining of specific quadriceps activity and activation but without significant pain or perceived exertion levels. It has been suggested that to gain acute

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changes in quadriceps torque and activation levels there are generally two options: the use of external dis-inhibitory interventions, such an example is cryotherapy⁸; or external facilitators such as muscle stimulation.¹⁴ An alternative method to consider is the use of exercises that specifically induce a higher level of automatic or innate activation of the required muscle groups.^{13,15} However, there is debate as to whether preferential strengthening or activation of the quadriceps can be affected by altering lower limb joint orientation or muscular co-contraction.¹⁶ If the quadriceps are selectively activated by the innate process of simply performing the activity, then subsequent recruitment and control will be facilitated. It is advocated that the action of innate or involuntary muscle activation focuses the individual's ability to the required activation and facilitates subsequent control of the required muscle in the voluntary and active settings.^{13,15} This aspect of knee exercise and quadriceps activation is an area where further research has been recommended.¹⁶

The activity of slacklining is defined as 'the action of retaining balance while standing or moving on a tightened band'.¹⁷ It has been demonstrated to activate or provide training-induced improvements in the rate of force development in lower limb activity,^{18,19} prevention of injury in elite athletes,²⁰ postural stability²¹ and postural control²² as a more challenging exercise for the knee and hip joints than multi-functional rocker boards and air cushions.²³ Slacklining has also been reported to reduce patella subluxation within a physiotherapy supervised exercise programme²⁴ and enhance functional knee joint stability through preparatory activation of the rectus femoris muscle.²² This action is coupled with the ability to provide learned motor control, such as down regulation of the Hoffman reflex, as well as a training effect and mechanisms that are pre- rather than post-synaptic.¹⁷ Given that balance and strength promotion are important for injury prevention, the use of an activity such as slacklining should be investigated in the early rehabilitation phase.^{18,19,21} This study aimed to investigate the effectiveness of slacklining as a rehabilitation exercise in spontaneously inducing quadriceps activation in the clinical rehabilitation environment.

2. Methods

Design: An observational cross-sectional cohort with a single-session measurement set was used. This cohort was used to investigate and compare slacklining and the level of quadriceps activation (dependent variable) achieved during three different knee exercises (independent variable) of (i) traditional clinical based open kinetic chain, (ii) closed kinetic chain, and (iii) composite kinetic chain.

Participants: Participants ($n=49$) with an age range of 13–72 years (41.8 ± 16.8 , 57% female) were recruited from a physiotherapy outpatients setting. A total of 51 participants were recruited with three cases eliminated that were three standard deviations outside the mean or equivalent to 0.12% chance of being part of the intended population of interest. Inclusion criterion were a knee injury sustained within the preceding two weeks. Exclusion criteria were red flag signs, including fracture, age <13 years and inability to understand spoken English. A total of 18 different conditions presented including soft tissue injury, pre- and post-operative, degenerative and overuse (Table 1). Written informed consent was gained and all participant information was de-identified to ensure anonymity and compliance with ethical standards of the University of the Sunshine Coast Human Ethics Committee as per the approval number A/12/434.

Procedures: Participants completed five separate quadriceps exercises in the clinical setting at a self-perceived effort (PE) of a 'strong to maximal contraction'. This method was chosen as it

Table 1
Population demographics.

Sample characteristics	Value
Number of participants	49
Age (years; mean \pm SD)	41.8 \pm 16.8
Gender (% female)	57%
Diagnosis	Number
Anterior cruciate ligament Dysfunction	3
Ilio Tibial Band friction syndrome	1
Lateral Collateral ligament	1
Medial Collateral ligament	11
Meniscus – no tear	2
Meniscus – tear	3
Osteoarthritis	6
Osgood Schlatters	1
Patella tendon	2
Patello-Femoral Joint	5
Pes Anserinus	1
Post-operative Menisectomy	3
Post-operative PFJ debridement	1
Proximal Calf strain	3
Soft tissue injury – non-specific	1
Swelling – non-specific	1
Weakness – non-specific	1

replicated the clinical rehabilitation situation, rather than a controlled laboratory environment. These exercises included four standard quadriceps rehabilitation exercises: two open-chain exercises¹³ of an inner range quadriceps (IRQ) contraction through the final 30 degrees of knee extension over a foam roller, and; a straight leg raise (SLR), a contraction of the extended knee then lifting the limb from the resting surface. The two closed-chain exercises¹³ of both a step-up and a step-down off a standard height house-step of 200 mm.²⁵ An example of the slackline activity, Stage 1 – Step 1 'Stepping up' is shown in Fig. 1 which²⁶ is considered



Fig. 1. Slacklining Stage 1, Step 1 from Gabel and Mendoza, IJATT, 2013.

Table 2

Means, standard errors, and 95% confidence intervals for quad activation in each group.

Quad	Mean	Std. error	95% Confidence interval	
			Lower bound	Upper bound
IRQ	128.082	12.772	102.403	153.761
SLR	120.816	10.865	98.970	142.662
Step Up	127.327	10.835	105.541	149.112
Step Down	135.653	11.958	111.611	159.696
Slackline	192.408	14.802	162.646	222.170

as the first and simplest activity involved in slacklining.^{26,27} The Slackline employed in this study was a 'Fun Line' manufactured by Gibbon, anchored at a length of 3 m and a height of 25 cm. The perceived effort was recorded after each category of open-chain, closed-chain and slackline (composite-chain) on an 11-point numerical rating scale (NRS) anchored at 0 = no perceived effort and 10 = maximum perceived effort.

Participants were permitted two familiarisation test trials for each exercise and then repeated each exercise three times. The five exercises were performed in the same order by all participants. The median score was recorded from the digital output on a 'Neurotrac Myoplus' (Verity Medical UK) using skin-mounted electromyography electrodes in a longitudinal configuration.²⁸ This system provided both audio and visual biofeedback to the participant and ease of recording of the digital output. Active encouragement from the therapist was not provided during the exercise, only through the initial instructions described and the EMG dual outputs. A one-minute rest was taken between each different exercise.

Statistical analyses: A simple repeated measures analysis of variance (RMANOVA) was performed with each type of activity (inner range quadriceps, straight leg raise, step-up, step-down, and slackline) as the within-subjects variable. Standardised residuals were examined to eliminate within-cell outliers. There were 49 cases in the final sample to be analysed. Because the hypothesis was testing whether slackline activity produced different results from the other four traditional activities, *a priori* simple contrasts were requested comparing that outcome to each of the other four. Mauchly's test of sphericity was significant (indicating this assumption was violated) and thus, Greenhouse–Geisser corrected statistics are reported.

For the analyses of perceived effort, similar analyses were performed. The first perceived effort measure was taken after inner range quadriceps and straight leg raise, the second after step-up and step-down, and the third after the slackline activity. Thus, the last was compared to the first two via *a priori* simple comparisons.

3. Results

The population demographics are detailed in Table 1.

Results of the RMANOVA indicated a significant *F* for the within-subjects analysis ($F_{(2.52, 121.00)} = 21.53, p < 0.0001$). Importantly, there was an impressive eta squared of 0.31, indicating that 31% of the variance in quadriceps activation was accounted for by activity (supplementary Table 1).

The findings shown in Table 2 demonstrate that quadriceps activation for slackline activity was much higher than any of the other four groups, which were largely equivalent. The 95% confidence intervals (CIs) for the first four groups, for example, overlap almost completely, whereas the 95%CI for slackline does not overlap at all with any of the other four. This leads to highly significant contrasts between slackline activity and the other four groups (supplementary Table 2). Consequently, we can conclude that quadriceps activation via slackline activity is significantly (and substantially)

Table 3

Means, standard errors, and 95% confidence intervals for effort in each group.

Effort	Mean	Std. error	95% Confidence interval	
			Lower bound	Upper bound
IRQ/SLR	6.867	.269	6.326	7.409
Step	6.745	.236	6.271	7.219
Slackline	4.684	.316	4.048	5.319

different to any of the other four, which are largely indistinguishable from each other.

When perceived effort was examined, the opposite effect was observed. Again, the assumption of sphericity was violated, so Greenhouse–Geisser corrected statistics are reported. There is a highly significant difference across groups ($F_{(1.62, 77.70)} = 26.88, p < 0.0001$) with a large effect size or eta squared = 0.36 (supplementary Table 3). Importantly, as Table 3 shows, the first two perceived effort scores during the open and closed kinetic chain activity are largely equivalent, while the perceived effort during slackline activity was significantly lower than either of the first two measures (supplementary Table 4).

4. Discussion

The main findings of this study demonstrated that slacklining, as an exercise for rehabilitation of the knee in the acute injury phase, enabled a statistically higher level of quadriceps activation to be achieved than traditional open- and closed-chain exercises. Furthermore, this level of activation is achieved by the injured individual at a lower level of perceived effort. Consequently, we have an activity that provides substantially enhanced quadriceps activation with substantially reduced perceived effort.

Previous research has found that closed-chain exercises, such as step-ups and unilateral leg press exercises, had the greatest levels of quadriceps activation and that the straight leg raise had the highest level for open-chain exercises.¹³ The use of slacklining provides a composite-chain exercise that appears to garner the optimal aspects of both the open- and closed-chain activities.

The findings of this study support the recent arguments that perceived effort during dynamic whole body exercise is independent of the physiological attributes of afferent feedback, such as that from small-diameter muscle of the heart, and lungs.²⁹ It also supports the arguments that perceived effort for isolated and/or isometric exercises, such as those found in the basic stance action of slacklining as tested in this study, are independent of the sensory inputs from muscle spindles and Golgi tendon organs.³⁰

These results also support earlier work that suggests that slacklining can be beneficial in providing both a prophylactic^{20,24} and a rehabilitation action.^{18,19,21} The results of this work when viewed within the context of earlier slackline research findings and those of perceived effort from both the afferent and sensory input perspectives, support the concept of innate activation of specific muscles during dynamic whole body activities.^{13,15}

The findings of this study indicated support for the adaptive plasticity in humans of the Hoffman reflex³¹ as participants were rapidly able to reduce the level of wobble or co-contraction that is initially present on first commencing a single leg stand on a slackline.²⁶ Furthermore, this finding was consistent among participants supporting previous research that this adaptation is a reliable indicator of changes in the neuromuscular system.³² This study supported the contention that the use of the skin mounted EMG is a simple, inexpensive and valuable adjunct to conventional therapeutic modalities. The procedure with EMG bio-feedback in the early phase of rehabilitation enhances knee control and facilitates innervation of the quadriceps, a key criterion in the regaining of knee extension and postural control.³³ There may be a central

nervous system effect that provides a bilateral effect and such a neurophysiological change would be an asset to clinical rehabilitation for the lower limb.

The study used a small population of consecutive participants from a physiotherapy setting and consequently cannot be extrapolated to other more diverse situations. The use of surface EMG in a longitudinal array is a clinical tool but argued as less accurate than other methodological techniques as such as laboratory based fine wire insertion. This study did not differentiate between the different injury presentations but considered the participants as a homogenous group. However, it is well documented that different conditions will have different levels of inhibition based on the degree of trauma and swelling, factors that were not taken into account during this study.

The strengths are that the study replicates the clinical situation and has direct application to the daily practice of individual knee injury rehabilitation. The activity is easy to perform, easy to learn and low risk. Consideration of the knee injuries as a homogenous group indicated that the application of slacklining in rehabilitation to overcome quadriceps inhibition is a realistic and clinically viable exercise.

Future research will be able to investigate the specifics of quadriceps activation during slacklining on different individual injury categories such as ACL as opposed to patella-femoral joint dysfunction or osteoarthritis. The implications are that slackline exercises can also be transitioned with equal effectiveness into the rehabilitation and management of ankle and hip as well as core and whole body stabilisation work. Laboratory based studies will be required and also the determination of whether there is an age or gender based bias. Additional whole body balance approach activities such as rocker board and air cushions also facilitate quadriceps function and may be an area of further consideration.²³ Similarly, the use of outcome tools such as the Balance Error Scoring System or Star Excursion Balance Test could be used bilaterally to determine whether a central change had occurred due to the use of slacklining.

5. Conclusions

The use of slackline rehabilitation training in the clinical setting can provide significant increases in activation and recruitment of the quadriceps muscles. This activation occurs spontaneously at significantly lower levels of perceived exertion in a manner that appears to be selective and simple to achieve. This suggests that slacklining could be a valuable adjunct exercise for lower limb rehabilitation programmes, particularly in the outpatient setting and in circumstances where the quadriceps are inhibited and activation is required.

Practical implications

- This method is complementary for use in the outpatients rehabilitation setting.
- The techniques can be used with external electromyography (EMG) biofeedback in a practical setting with ease and simplicity.
- The exercises are rapidly transferable to a home programme for individual rehabilitation and training.
- The exercise provides a practical approach that enables rapid activation of the medial quadriceps for teaching, rehabilitation and re-education.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jsams.2013.11.007>.

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