Familiarisation to maximal recumbent eccentric cycling

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Abstract.
BACKGROUND: Isokinetic eccentric cycling is increasingly being utilised to examine the effect of chronic eccentric muscle training however little is known about how individuals familiarise to such a unique training modality.
OBJECTIVE: To examine longitudinal variation in power output and lower limb muscle activation during familiarisation to maximal recumbent isokinetic eccentric cycling.
METHODS: Twelve male volunteers, unfamiliar with eccentric cycling, completed four trials, separated by 7–10 days, each comprising 6 × 10 s maximal isokinetic eccentric efforts between 20–120 rpm. Peak power and average power output (PO), and surface electromyography (sEMG) of the *rectus femoris* (RF), *vastus lateralis* (VL), *biceps femoris* (BF), and medial *gastrocnemius* (MG) were recorded throughout. Systematic error across repeated trials was assessed using one-way ANOVA, and random error quantified using coefficient of variation (CV, %).
RESULTS: Average PO at 60 rpm and RF activation at 20 rpm increased from trial 1–2 ($p < 0.05$), with no other systematic error between trials at any cadence. Across all cadences, the CV for peak PO (∼13%), average PO (∼10%), VL activation (∼13%) and RF activation (∼19%) was moderate and plateaued after one familiarisation (i.e. T2–T3). However, for BF (∼24%) and MG (∼22%) activation reliability was generally poor. For the majority of variables the reliability was best at 60 rpm.
CONCLUSIONS: Therefore, with one familiarisation, 60 rpm is recommended to achieve moderate between-session reliability in the measurement of power output and lower limb muscle activation during recumbent, eccentric cycling.

Keywords: Eccentric cycling, familiarisation, electromyography; reliability, power output

1. Introduction

It is well documented that isolated eccentric contractions can produce up to twice the force of concentric or isometric contractions [1–4]. Similar findings have also been observed in eccentric cycling where, for the same metabolic cost, up to three times greater power can be produced compared to concentric cycling [5,12]. Furthermore the electrical activity (detectable with surface electromyography) at any given power or force production is less during eccentric compared to concentric exercise [3,6]. Collectively these indicate that eccentric cycling may offer a potent stimulus for musculoskeletal adaptation by being a training modality that is non weight bearing, ‘relatively’ low in metabolic cost, but can also put greater stress on the muscle-tendon complex through higher levels of tension not possible under concentric loading. An additional advantage of eccentric cycling ergometry is the ability to prescribe high-volume, specific eccentric work that minimises the concentric contractions typically associated with other types of cyclical eccentric training, such as traditional free-weight resistance exercise. Training studies utilising eccentric cycling have observed notable increases in *vastus lateralis* cross-sectional area [7], jump power, leg stiffness [8], concentric power, pennation angle [9], and jump height [10], supporting the posit that eccentric cycling can offer a potent training stimulus.

Given eccentric cycling is likely a novel stimulus for the majority of participants, it is important for both researchers and practitioners to understand the time-course of familiarisation in order to optimise measurement and exercise prescription. Brughelli & Van Leemputte [11] concluded that two familiarisations are required to ensure a good level of within-subject reliability for power output in maximal eccentric cycling. However, this research was conducted on an upright ergometer as opposed to a recumbent bike, the latter being more commonly used in eccentric cycling research [8,9,12]. In concentric cycling, differences in body orientation (between conventional cycling position and recumbent) are known to significantly alter power output and muscle activation [13,14]. Therefore it is reasonable to suggest that similar differences might also be present in the eccentric domain.

The evidence around the learning response to recumbent eccentric cycling is limited. For example, greater consistency maintaining a given power output was observed after six weeks of recumbent eccentric cycling at 60–80 rpm [10], however, this does not offer insight to the initial, session-by-session, learning effect. Penaillillo et al. [6] reported reductions in *vastus lateralis* activation for a set power output at 60 rpm after two sessions, indicating a change in neuromuscular activation, but no other muscles or cadences were tested. Additionally, very little is known about the effect of cadence on the familiarisation process to recumbent eccentric cycling. It has been suggested that during upright eccentric cycling the between-session power output at low cadences (40 rpm) is less reliable in comparison to higher cadences (60–120 rpm; [11]), however this posit has yet to be tested in recumbent eccentric cycling. A greater understanding of the muscle activation that underpins pedalling technique, across a range of cadences, would help optimise the prescription of eccentric cycling. Furthermore, when combined with power output data, it would highlight the number of pre-trials required to attain repeatable results after which interpretations can be made on interventions and progression. Therefore, the aim of this study was to identify the reliability of measures of power output and lower limb muscle activation during the familiarisation to recumbent eccentric cycling and over a range of cadences, to recommend the number of practice trials required to minimise variation.

2. Methods

2.1. Subjects

Twelve recreationally active males (mean ± SD; age = 37.5 ± 6.7 years; body mass = 76.1 ± 6.7 kg; stature = 181 ± 6 cm) with no history of lower limb injuries or neurological disorders volunteered to undertake this investigation. All participants provided written informed consent and were deemed healthy as determined by a physical activity readiness questionnaire. Participants were asked to refrain from caffeine, alcohol and exercise in the 24 hours preceding each trial and maintained their habitual training throughout the testing process. Ethical approval was granted prior to the start of all procedures by the Northumbria University Faculty of Health and Life Sciences Ethics committee, in accordance with the Declaration of Helsinki.

2.2. Experimental design

To establish the familiarisation time-course of the variables under investigation, participants performed maximal eccentric recumbent cycling bouts at a range of cadences on four separate trial days. Ten days separated trials one and two with the remaining trials each separated by seven days. All exercise was performed on a custom built, recumbent, isokinetic cycle ergometer. During each visit participants completed six, 10 s maximal bouts of eccentric cycling in a randomised, counterbalanced (Latin squares method) order at 20, 40, 60, 80, 100 and 120 rpm with 5 min recovery between each bout. The dependant variables were peak power output (PO), average PO, and muscle activation of the *rectus femoris*, *vastus lateralis*, *biceps femoris*, and medial *gastrocnemius*.

2.3. Eccentric ergometry

All exercise was conducted on a custom built recumbent cycling ergometer (BAE systems, London, UK). A 2200 W motor powered the pedals in either a clockwise or anti-clockwise direction at a pre-set cadence in an isokinetic manner. Participants either pushed with or resisted against the direction of movement in order to conduct concentric or eccentric muscle actions, respectively. Rigid, carbon fibre soled, cycling shoes (Bontrager Riot RR-45, Trek, USA) and Look Keo pedals (Look Cycle, France) were used to maintain a consistent participant-ergometer interface and participants were instructed to remain seated. Torque data was obtained from a calibrated strain gauge located on the crank arm via a wireless telemetry system (Mantracourt Electronics, UK). Data were sampled at 200 Hz, digitised and acquired using an A/D converter (CED 1401, Cambridge Electronic Design, UK) for off-line analysis (Spike 2 version 8.02, Cambridge Electronic Design, UK). In order to establish a relationship between torque and sEMG activity, torque and sEMG values from the left limb and crank were used for analysis.

Power values were calculated from torque data using the following equation:

$$\text{Power (W)} = \text{Torque}(N \cdot m) \times \text{Cadence}(rad \cdot s^{-1})$$

Peak PO was derived from the peak instantaneous power during each 10 s effort and average PO was calculated for the entirety of each 10 s effort. Immediately prior to each 10 second maximal sprint, participants were given 30 seconds to familiarise themselves with the cadence (i.e. not resist the pedals but instead be passively moved by them); this was the only eccentric familiarisation afforded to them. Participants were instructed to resist the pedals in the opposite direction of motion. After this familiarisation a one minute rest was observed before commencing the 10 s maximal effort. For each 10 s effort the participant began by having their legs passively turned by the ergometer, to ensure the correct cadence was attained, before being counted down to initiate the effort. The elapsed time was hidden from the participant, but the participant was informed when each 10 s epoch had expired and the ergometer was subsequently stopped.

2.4. Surface electromyography (sEMG)

For each muscle of interest, two, 20 mm diameter electrodes (Ag/AgCl; Kendall 1041PTS, Covidien, Mansfield, MA, USA) with an inter-electrode distance of 20 mm were placed according to the SENIAM guidelines for EMG placement [15] on the left leg. The muscles used for analysis were the *rectus femoris* (RF), *vastus lateralis* (VL), *biceps femoris* (BF) and medial *gastrocnemius* (MG). The skin was shaved and abraded with an alcohol swab. A reference electrode was placed on the patella. The positions of the electrodes were marked with indelible ink to ensure a consistent placement between trials. Electrode signals were amplified (× 1000; acquired via 1902, Cambridge Electronic Design, Cambridge, UK), 50 Hz notch filtered, band-pass filtered (20–2,000 Hz), sampled at 2 kHz (CED 1401, Cambridge Electronic Design, UK), and analysed off-line (Spike 2 version 8.02, Cambridge Electronic Design, UK). For normalization of sEMG measures, at the start of each trial participants completed three 8 s maximal voluntary concentric contractions (separated by 5 mins) at 1 rpm between a pedal angle of 0° (top dead centre) and 48°. Using a 0.2 s root-mean-square (RMS) window, the maximum sEMG activity from the three MVC efforts for each muscle was used to obtain a reference value for normalization purposes. Muscle activation during the maximal 10 s efforts was calculated as the average RMS value for the two whole revolutions that corresponded to the greatest power output. This was in order to compare different cadences over an identical range of motion.

2.5. Statistical analyses

All statistical testing was performed using Graph Pad Prism 7.00 (GraphPad Software Inc, California, USA) and Microsoft Excel 2010 (Microsoft, Washington, USA). To assess systematic error between trials for peak PO, average PO and EMG, data were analysed using one-way repeated measures analysis of variance. Where appropriate, Tukey's *post-hoc* test was used to locate any significant differences. Significance was set at an alpha level of 0.05. The random error associated with familiarisation of the task was assessed across successive trials using coefficient of variation (CV, %) calculations ± 95 confidence limits. Reliability was defined as the extent to which the experimental trials yielded the same results on repeated trials. Coefficient of variation values were classed as good (< 5%), moderate (5–10%), or poor (> 10%) based upon values observed previously in maximal concentric cycling < 10 s [11,16,17].

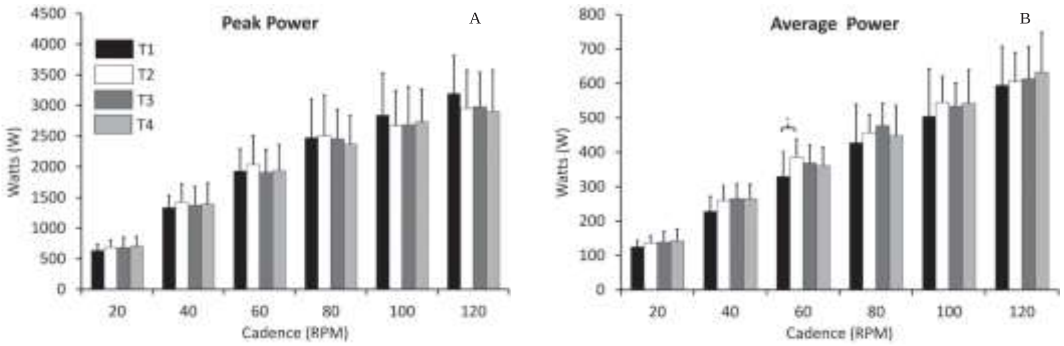

Fig. 1. Peak power (A) and average power (B) data during repeated trials of maximal recumbent eccentric cycling exercise at varying cadences ($n = 12$). Values are mean (SD) * denotes significant difference at $p < 0.05$.

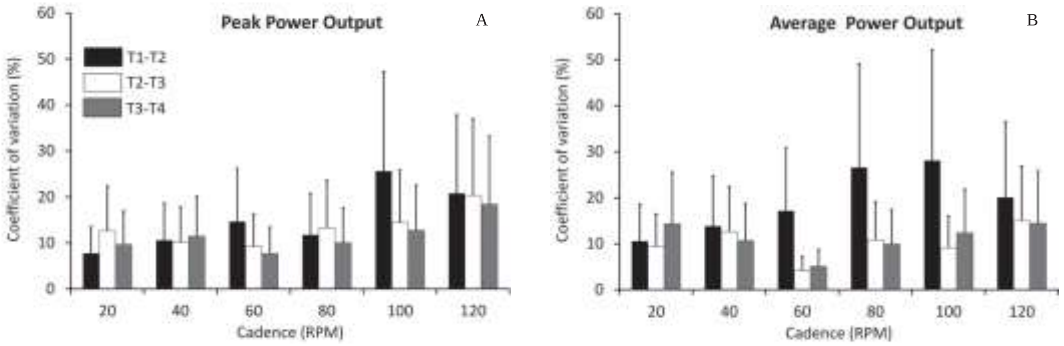

Fig. 2. Between-session coefficient of variation data for peak power (A) and average power (B) output for repeated trials of maximal recumbent eccentric cycling exercise at varying cadences ($n = 12$). Values are mean (95% CI) * denotes significant difference at $p < 0.05$.

3. Results

3.1. Power data

Figure 1 shows the mean values (± SD) for peak PO and average PO across all trials. There was a significant effect of trial on average PO at 40 rpm ($F_{(3,33)} = 3.006$, $p = 0.044$) and 60 rpm ($F_{(3,33)} = 4.913$, $p = 0.006$). *Post-hoc* testing revealed that at 60 rpm average PO at T2 was greater in comparison to T1 ($p = 0.004$), with no other differences thereafter (all $p > 0.05$). For 40 rpm, the Tukey *post-hoc* adjustment to limit type 1 errors from multiple comparisons resulted in no statistical differences between trials, though PO in T1 tended to be lower than subsequent observations (T1–T2, $p = 0.15$; T1–T3, $p = 0.07$; and T1–T4, $p = 0.07$), but with no change thereafter (T2–T3, $p = 0.98$; T3–T4, $p = 0.99$, Fig. 1, panel B). There were no other differences in average PO or peak PO between trials at the other cadences. Between-trial CV for peak PO and average PO, including 95% confidence limits, are displayed in Fig. 2. The greatest reduction of between-session CV for peak PO (T1–T2, 8–26%; T2–T3, 9–20%) and average PO (T1–T2, 11–28%; T2–T3, 4–15%) was seen after one familiarisation session, i.e. between T2–T3, with little further improvement thereafter (peak PO, T3–T4, 8–18%; average PO, T3–T4, 5–15%). Between cadences, the lowest CV values were observed at 60 rpm for both peak PO (T2–T3, 9%; T3–T4, 8%) and average PO (T2–T3, 4%; T3–T4, 5%). Furthermore, there was a tendency for faster cadences (;? 80 rpm) to initially (T1–T2) display larger CVs in comparison to slower cadences (60 rpm) in both peak PO (11% vs 19%, Fig. 2, panel A) and average PO (14% vs 25%; Fig. 2, panel B).

3.2. EMG data

Mean values (± SD) for all muscle activation variables are displayed in Fig. 3. There was a significant effect of trial on RF activation at 20 rpm ($F_{(3,33)} = 6.038$, $p = 0.002$). *Post-hoc* analysis revealed greater activation at T2 ($p = 0.003$), and T4 ($p = 0.006$) in comparison to T1, and generally RF activation tended to increase with repeated trials (Fig. 3, panel C). Similarly, at all cadences, MG activation tended to increase

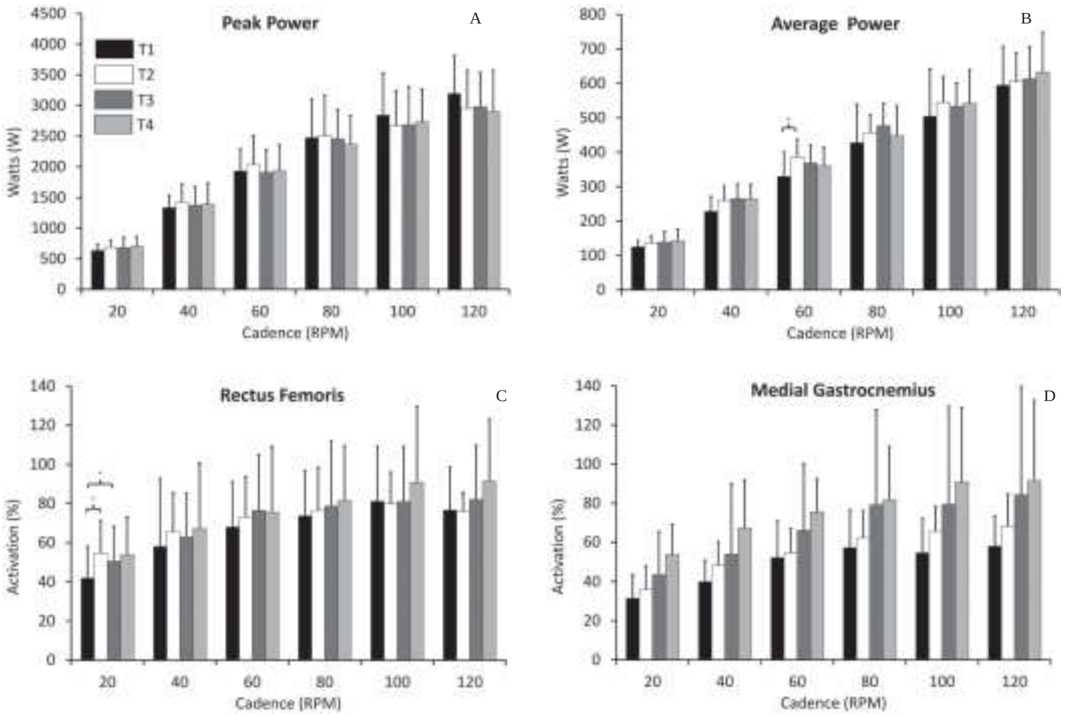

Fig. 3. *Biceps femoris* (A), *Vastus lateralis* (B), *Rectus femoris* (C), and Medial *gastrocnemius* (D) activation data during repeated trials of maximal recumbent eccentric cycling exercise at varying cadences ($n = 12$). Values are mean (SD) * denotes significant difference at $p < 0.05$.

with repeated trials (Fig. 3, panel D), although this difference was not statistically significant at any cadence (all $p > 0.05$). No such patterns were observed in BF or VL activation. Between-trial CV data for muscle activation, with 95% confidence limits, are displayed in Fig. 4. The majority of EMG CV variables decreased with repeat trials (Fig. 4). This reduction in CV was consistently observed after one familiarisation, before plateauing, with the VL (T2–T3, 9–16%; T3–T4, 8–15%) and RF (T2–T3, 14–26%; T3–T4, 12–20 %) across all cadences. However, no such plateau was observed with BF (T2–T3, 30–48%; T3–T4, 15–35%) and MG (T2–T3, 27–51%; T3–T4, 13–32%; Fig. 4).

4. Discussion

The aim of this study was to establish the time-course of familiarisation to maximal recumbent isokinetic eccentric cycling, and to determine the reliability of this mode of exercise for a range of cadences. The data suggests that at least one practice trial is required to achieve consistent group means and good to moderate between-session reliability in peak PO and average PO, with 60 rpm displaying the greatest reliability. To improve the reliability of selected lower limb muscle activation variables at least one practice trial should be employed (VL and RF). However, to increase the reliability of sEMG in other lower limb muscles (BF and MG) further familiarisations would be prudent, and even with this level of experimental control between-session variability could still be unacceptably high.

The absence of significant changes in average and peak PO after T2 indicates that one familiarisation reduces variation sufficiently to attain consistent PO data. This notion is supported by the plateau in average and peak PO CV between T2–T3 and T3–T4 which further indicates that only one familiarisation would be sufficient to minimise the initial, large, variability observed in the current investigation. A similar time-course of familiarisation has been previously observed in upright eccentric cycling where a plateau in average PO was identified after one familiarisation session, although consistent between-session CVs required an additional familiarisation [11]. Brughelli & Van Leemputte [11] also observed an increase in peak PO and its reliability after two and four sessions respectively. In contrast, the current study found no change in peak PO, and little discernible change in peak PO reliability after

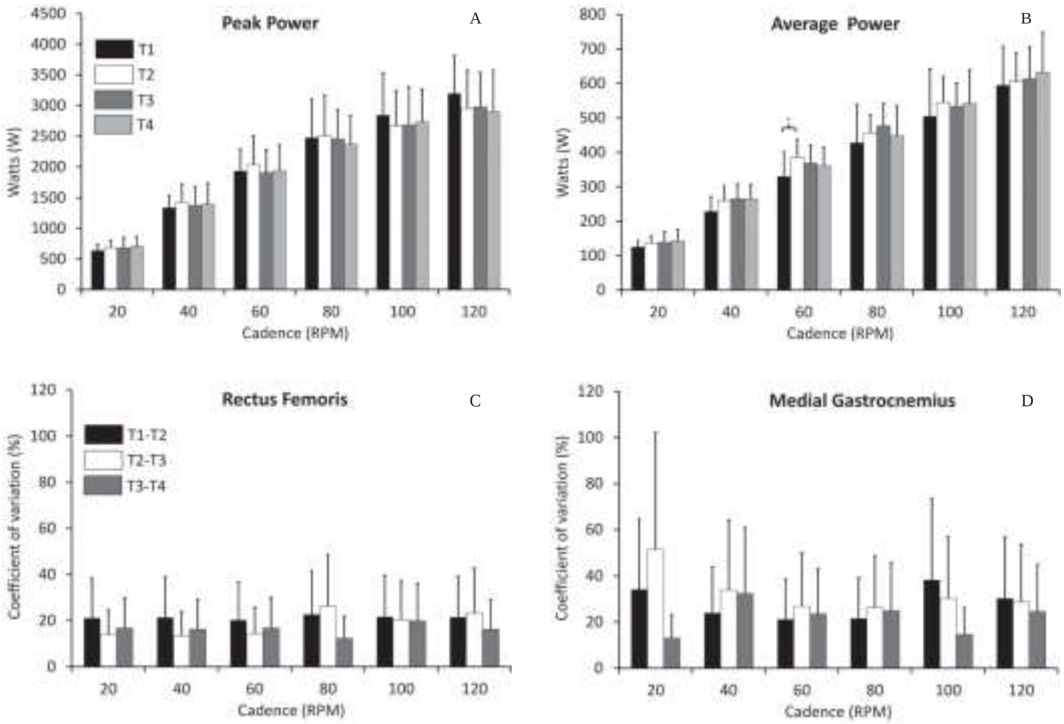

Fig. 4. Between-session coefficient of variation data the *biceps femoris* (A), *Vastus lateralis* (B), *Rectus femoris* (C), and Medial *gastrocnemius* (D) for repeated trials of maximal recumbent eccentric cycling exercise at varying cadences (n = 12). Values are mean (95% CI) * denotes significant difference at $p < 0.05$.

T2. This discrepancy in peak PO and peak PO reliability might stem from the larger absolute peak PO in the current study (↑ ~100%), even though a similar population was sampled. One possibility is that different factors limit peak PO during upright and recumbent eccentric cycling and that these factors are reduced during recumbent cycling, hence the greater power output. Furthermore, greater initial peak PO would reduce the capacity for improvement which may explain the absence of changes in peak PO in the current study in comparison to [11]. This absence of change in peak PO, combined with the increases in average PO, suggest that participants developed a more consistent pedalling technique, rather than a more powerful technique, as they became familiarised to maximal recumbent eccentric cycling.

We demonstrated a trend for increased RF and MG activation during the initial stages of familiarisation to maximal, recumbent, eccentric cycling. Similar findings have also been observed in isolated eccentric contractions and attributed to a reduction in neural inhibition [18,19]. Neural inhibition is thought to limit muscle activation to protect the muscle-tendon unit from high forces that would otherwise cause damage. However, for the purposes of eliciting a training response, it is likely that these high power outputs make eccentric cycling a potent stimulus. The ability to fully activate the muscle during eccentric cycling could promote greater adaptation. Therefore, before the full potential of eccentric cycling as a training stimulus can be realised, or studied, a thorough familiarisation plan should be considered. Although the significant changes in RF activation (20 rpm) ceased after T2 there was a tendency for MG and RF activation to increase from T1 to T4. This tendency for increased activation across trials was not evident with the BF or VL. It is possible that because maximal recumbent eccentric cycling did not elicit the same high muscle activation in the VL and BF in comparison to the RF and MG that these muscles did not experience a large enough stress to elicit an increase in activation with subsequent trials. Given that all monitored muscles do not have the same role in this unique movement it is not surprising that they have responded differently to the familiarisation process. At any given cadence, or trial, muscle activation was, in the majority, greatest in the RF (~77%) followed by the MG (~62%), VL (~52%), and BF (~37%). This supports work by Elmer et al. [8] that found eccentric actions of the knee extensors and ankle extensors absorb significantly more power during eccentric cycling in comparison to the knee flexors.

Previous research has observed the between-session CV of sEMG to be 16% during maximal isometric contractions [21] and between 20–78% during a dynamic movement such as cutting [22] or walking [23]. This suggests that the CV values of ~13% (VL) and ~16 % (RF), in the current study, are favourable when compared with other dynamic movements. However, more concurrent with previous research are the worse CV values observed in the BF (~24%) and MG (~22%). Considering that the BF does not play a key role in power absorption during eccentric cycling [20] this worse reliability is not surprising. However, the MG does play a role in power absorption yet displays markedly worse reliability in comparison to other prime movers such as the VL and RF. Anecdotally participants found coordinating the ankle joint the most difficult task during each maximal eccentric effort. It is possible that a large portion of the variability in power output could be a result of high variability in MG activation. Therefore it may be prudent to focus a user on maintaining a consistent ankle joint orientation during familiarisation to recumbent isokinetic eccentric cycling.

To account for the acute changes in PO and lower limb muscle activation during the familiarisation to maximal recumbent isokinetic eccentric cycling it is recommended that at least one familiarisation session be prescribed. Furthermore, after one familiarisation session, moderate between-session reliability can be attained in peak and average PO, and VL and RF activation. However, in order to improve the reliability of

BF and MG activation it may be prudent to adopt at least two familiarisations, although this is unlikely to result in improving reliability to acceptable levels. Fi- nally, a cadence of 60 rpm is recommended in order to achieve the greatest reliability in the aforementioned variables.

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We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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