Reliability of Traditional and Task Specific Reference tasks to assess Peak Muscle Activation during two different Sprint Cycling Tests.

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ABSTRACT

Neuromuscular activation is considered an important determinant sprint cycling performance but requires reliable EMG amplitude measurements to facilitate sensitive assessments. The reliability of EMG measurements during sprint cycling may depend on the sprint cycling test undertaken (isovelocity or isoinertial accelerating), the reference tasks used for normalisation (isometric MVCs of a series of single muscle groups [ISO-SINGJT] or isometric cycling MVCs [ISO-CYC]), and the efficacy of the normalisation. This study aimed to compare the magnitude and between-session reliability of peak muscle activation (peak rmsEMG) during: isovelocity and isoinerital sprint cycling tests; ISO-SINGJT and ISO-CYC reference tasks; and absolute and normalised EMG during the sprint cycling tests.

EMG amplitude was measured over six major muscle groups on both legs and all measurements were made over two sessions in a randomised counterbalanced design. Peak rmsEMG was assessed during both ISO-SINGJT and ISO-CYC MVCs and then during mechanical peak power output (PPO) during isovelocity (120 RPM) and isoinerital acceleration (0 to >150RPM) sprint tests. Absolute peak rmsEMG and for the sprint tests normalised EMG values were determined, and coefficient of variation and intra-class correlation coefficients used to assess reliability.

Peak rmsEMG at PPO during both sprint cycling tests was similar for the six muscle groups measured. Peak rmsEMG was higher during ISO-SINGJT than ISO-CYC for for 3 of the 6 muscle groups, but all muscle groups exhibited similar reliability for both reference tasks. Neither reference task improved the between-session reliability for either sprint test. This data highlights reservations in the use of isometric reference tasks to ascertain changes in peak muscle activation over time in during sprint cycling assessments.

INTRODUCTION

Sprint cycling lab tests typically are short in duration (<7s) and maximal in effort in order to measure peak mechanical power output (PPO) (Dorel et al., 2005; Martin et al., 2007) and associated biomechanical and physiological aspects of performance. Two lab tests are commonly used to measure PPO in sprint cycling. Firstly, isoinerital accelerations where the participant pedals maximally against a constant inertial load for 5 – 7 s from a stationary start with the aim of accelerating the pedals to the highest cadence as quickly as possible (Martin et al., 1997). Secondly, the isovelocity method involves maximal sprinting at a constant, pre-determined cadence for 3 – 4 s (Sargeant et al., 1981).

Neuromuscular activation is considered an important determinant of PPO and consequently sprint cycling performance (Driss and Vandewalle, 2013). However, there has been little research to understand the degree to which muscle activation, which can be assessed with surface electromyography (sEMG) measurements, influences PPO, or how neuromuscular activation changes with training. Before addressing these questions, it is important to establish if there are any differences in sEMG amplitude between sprint cycling tests (isoinertial vs isovelocity), the reliability of sEMG amplitude measurements during sprint cycling tests, and whether the reliability of sEMG measurements during sprint cycling tests can be improved by normalisation to an independent reference task. This will inform the interpretation and meaningfulness of any potential differences between athletes and/or changes in sEMG/muscle activation with training.

Normalisation of sEMG during a performance task, in this case sprint cycling, to sEMG during separate reference task(s), typically a series of isometric maximum voluntary contractions (MVCs) with each muscle group, is a widely recommended approach. The purpose of normalisation is to reduce the influence of variable signal recording conditions between-participants and -days, thereby improving reliability and reducing between-subject and between-session variability (Burden, 2010; Farina et al., 2014; Vera-Garcia et al., 2010). However, isometric MVCs with each of the muscle groups of both legs involved in cycling (potentially flexors and extensors of the hip, knee and ankle joints of each leg, thus 12 distinct isometric strength tests) is a laborious and time-consuming protocol and also relies on additional equipment (e.g. an isokinetic dynamometer). These single joint/muscle group MVCs also lack task specificity, as they are typically performed at different joint angles and involve activation of single muscle groups, in comparison to cycling. A novel reference task of isometric cycling involves all the cycling muscle groups simultaneously in each contraction (extensors of the front leg and flexors of the rear leg), which is therefore more specific to cycling, whilst also being a much more time efficient reference task (2 isometric strength tests, with each leg in front and rear positions). However, this idea has yet to be compared to traditional dynamometry, in terms of whether it produces equivalent sEMG amplitude values and reliability.

Accordingly, the aims of the experiment were: 1) to compare the magnitude and between-session reliability of peak muscle activation, assessed with sEMG amplitude, during two different sprint cycling tests (isovelocity and isoinerital); 2) to compare the magnitude and between-session reliability of sEMG amplitude during two different reference tasks (isometric single joint vs isometric cycling MVCs) in order to; 3) to establish if normalisation of sEMG amplitude during sprint cycling to reference tasks improves measurement reliability.

METHODOLOGY

Participants

Twelve trained male cyclists initially volunteered to take part in this study. However, only participants with complete performance and EMG data sets were analysed (i.e. EMG data collection for all muscle groups, for both limbs, for all reference tasks and performance tasks over both sessions). Three participants were excluded as had more than two electrodes completely detach from the skin during the experiment. As such, the data of twelve cyclists is presented (mean ± SD age, 27 ± 5 yr; stature, 182.9 ± 8.2 cm; mass, 84.0 ± 10.9 kg). The cyclists were predominantly competing in regional or national level track and road race competitions and all had been competitively racing for over 3 years. Following approval from Northumbria University Research Ethics Committee, participants provided written, informed consent prior to the experimental procedures. Cyclists were instructed to avoid caffeine and food for 3 h prior to testing and to avoid strenuous exercise in the 36 h before each session.

Protocol Overview

Participants attended the laboratory on four separate occasions; the first two visits were for familiarisation, followed by experimental session 1 (Exp 1) and experimental session 2 (Exp 2), each separated by 2-7 days, and conducted at the same time of day (± 1 h). Familiarisation and experimental sessions were identical apart from the recording of sEMG during the experimental visits. Experimental sessions started with placement of the sEMG electrodes followed by unilateral, isometric single joint (ISO-SINGJT) MVCs of four different muscle groups: the plantar flexors, hip extensors, knee extensors and knee flexors of each leg using an isometric dynamometer (Biodex, System 4 Pro, New York, USA). For each muscle group the right leg was always assessed first and then the left leg, before moving to the next muscle group. Following a passive rest period of 20-minutes, the participants then performed three MVCs of the isometric cycling task (ISO-CYC) with each leg as the front leg. Subsequently, the participants had a passive rest period of 10-minutes and then completed a standard 10-minute warm-up at on a modified cycle ergometer (Schoberer Rad Messtechnik, Jülich, Germany) (100–150 W, 80–90 revolutions per minute [RPM]) and then performed, in a randomised crossover order, isovelocity and isoinertial sprints. The isovelocity sprint involved a maximal effort at 120 RPM (with the ergometer in ‘isovelocity mode’) and the isoinertial sprints involved two maximal sprints accelerating from a stationary start with only the flywheel inertia as resistance.

Electromyography

Neuromuscular activation during all exercise tasks was measured using a wireless surface EMG system (Delsys Trigno® Wireless EMG systems, Boston, MA, USA). At the beginning of each experimental session, in accordance with standard SENIAM recommendations (Hermens et al., 2000), electrodes were placed on each leg over the gluteus maximus (GM); rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), long head of bicep femoris (BF) and lateral head of gastrocnemius (GL). To ensure optimal electrical conductance, each location was shaved, lightly abraded, and then cleaned with an alcohol wipe. The electrodes (inter-electrode distance = 10 mm, head size = 24 mm × 11 mm × 6 mm) were then applied using self-adhesive interfaces (Delsys Trigno®, Boston, MA, USA), each site was marked with a semi-permanent marker to ensure consistent placement across sessions. Surface EMG signals were amplified (×1000), band-pass filtered (20-450 Hz), sampled at 2,000 Hz using an external analogue-to-digital data acquisition system (Micro 1401, Cambridge Electronic Design, Cambridge, UK) and a PC utilising Spike2 software (version 7.11, CED, Cambridge, UK).

EMG Reference Task: Isometric Single Joint Dynamometry (ISO-SINGJT)

Single-joint, unilateral isometric (ISO-SINGJT) MVCs were performed using a calibrated dynamometer. Participants performed the MVCs seated and strapped across the hips and chest in the sagittal plane, in four different positions as previously performed by Kordi et al. (2017), these were selected because these joint angles were described as the angle of peak torque production for each muscle group (Ericson, 1986; Rouffet and Hautier, 2008). These MVCs were performed in the following order: plantar flexion (neutral or anatomical reference position (ARP), hip extension (45° flexed from ARP), knee extension (70° of flexion from the ARP), knee flexion (50° of flexion from ARP (Figure 1). The dynamometer configuration for each individual participant was recorded during the first familiarisation session and replicated thereafter. Muscle groups of both legs were assessed with the muscle groups on the right leg always being measured first. With each muscle group of each leg, participants completed three warm-up contractions of progressive intensity, before performing three MVCs, lasting 3-5 s, each separated by 60 s rest, with a further 5 minutes rest between muscle groups/legs. Prior to performing the MVCs, participants were reminded to perform the MVC "as hard as possible". Real-time bio-feedback, a torque-time trace displayed in front of the participant, and verbal encouragement was given throughout the MVCs. The real-time analogue torque signal was recorded by the same data acquisition system as for EMG recordings in order to synchronise the mechanical and electrical data.

EMG Reference Task: Multiple Joint Isometric Cycling Task (ISO-CYC)

Participants performed the multiple-joint isometric cycling task (ISO-CYC) on a custom-made instrumented cycling ergometer (BAE Systems, London, UK) that could be adjusted to make it isometric by fixing a modified clamp on the cast iron flywheel. The ergometer was adjusted to match the riders habitual cycling position. Once the cyclists mounted on the ergometer and attached their shoes using their clipless pedals, their forearms were positioned on the crossbar of the handlebars. The cranks were always first orientated with the right crank forward at 90° clockwise/at the 3 o'clock position from top, dead centre (TDC), and thus the left crank backward at 270° from TDC. Once in position, participants were instructed to try to 'pedal forwards as hard as possible with both legs whilst remaining in the saddle' (i.e., the front leg pushing down and the rear leg pulling up, simultaneously; Figure 1). After three progressive warm-up contractions, participants performed 3 MVCs each lasting 3 s that were separated by 60 s of rest. After 5-minutes of passive rest, the crank positions were reversed with the left crank positioned forward at 90° from TDC.

Sprint Cycling Methods

Both sprint cycling methods were performed on the same modified SRM cycle ergometer identical to the one used previously by Kordi and colleagues (Kordi et al., 2017). The geometry of the ergometer was adjusted to match the cyclist's racing position. Torque, cadence and subsequently power was measured using 170 mm instrumented cranks sampling at 200 Hz (Factor Cranks, BF1 Systems, Diss, UK) which was then wirelessly transferred and recorded on the data logger (Data logger, BF1 Systems, Diss, UK). This was then subsequently imported into the data acquisition software (Spike2) and analysed offline using custom scripts to calculate power (W) by multiplying torque (N.m) by cadence (revolutions per minute [RPM]). Crank data were synchronised with EMG recordings with a pulse generator (Maplin Electronics, Rotherham, UK) used to detect TDC of the drive side/right crank pulse. The pulse was also recorded in Spike2 in real-time during all cycling sprints. Participants wore their own cycling shoes and pedals (fitted to the ergometer) and participants were instructed to perform each recorded effort in the saddle whilst using the 'drop' handlebars.

Isovelocity Sprints

The isovelocity sprint method involved maximal cycling at a constant cadence of 120 RPM. This cadence was chosen as this the cadence where PPO is typically achieved. (Dorel et al., 2010; Elmer et al., 2011) Prior to each effort, the cranks were turned on and the motor speed was brought up to 120 RPM. The cyclists were then instructed to pedal lightly below the prescribed cadence and told to 'attack the effort as fast and as hard as possible' throughout each sprint. Cadence is kept constant using a braking module and a 2.2kW motor, riders could increase power output by increasing the torque throughout the crank revolution. The investigator gave a 3 s countdown and the subjects performed a 4 s maximal effort.

Isoinertial Sprints

The isoinertial sprint used the flywheel disc (mass of 4.6 kg) and the gear ratio (front 53; rear 17) to provide the resistance that the cyclists pedalled against. Prior to each sprint, the flywheel was brought to a complete standstill and participants assumed their preferred crank starting position (typically the front crank was between 45 – 90° from TDC). Participants were reminded to achieve the 'highest cadence possible by pedalling as hard and as fast as possible' and 'attack the effort as hard and fast as possible' before a 5 s countdown to a maximal sprint. After 6 s the investigator verbally terminated the test. Participants performed two sprints 8 min apart (Dorel et al., 2012). The sprint with the highest mechanical power output over a revolution (PPO) was used for analysis.

Data Analysis

For both sprint tests, PPO was identified as the highest mechanical power output averaged over a complete revolution (from TDC to TDC) for each test and subsequently used for EMG analysis (see Figure 2 as an example of isoinerital sprint test torque trace and an EMG channel). PPO and cadence at PPO (for isoinerital sprint test [cadence at PPO for the isovelocity sprint test was held at 120 RPM]) was recorded.

For the ISO-CYC reference tasks, the efforts with the highest peak instantaneous cumulative (i.e. sum of right and left crank) mechanical torque output during (for each side) was used for EMG analysis and for the ISO-SINGJT reference task, the effort with the highest peak torque for each muscle group during the respective was used for EMG analysis.

The isometric reference tasks had EMG signals processed as root-mean-square EMG amplitude (rmsEMG) with an epoch duration of 200 ms and the peak rmsEMG value was used. It has been suggested that when assessing isometric MVCs, time interval shorter than 200 ms significantly reduces reliability (Buckthorpe et al., 2012; Del Vecchio et al., 2018).

For the sprint cycling tests, peak rmsEMG was assessed as the highest rmsEMG during a 90° sector of crank displacement (i.e. ¼ of a revolution) during the revolution where PPO was achieved (measure from TDC to TDC) (Figure 2). Therefore, isovelocity sprints which were at a constant 120 RPM used a 125 ms epoch (as that is the time window equivalent to a 90° sector). For the isoinertial sprints, the revolution (measure from TDC to TDC) where mechanical PPO was achieved was used for analysis. The cadence was initially calculated by dividing 60 by time taken from TDC to TDC. Then the time window equivalent to a 90° sector was used for rmsEMG analysis. This ensured that all EMG measurements during both tests were assessed over a consistent range of motion despite different velocities.

Normalising the reference tasks (i.e. ISO-SINGJT or ISO-CYC) to the performance tasks was done so by dividing peak rmsEMG value of the performance task (of specific muscle) by peak rmsEMG value from the reference task (of said muscle). The resultant fraction was then expressed as a percentage.

Statistical Analysis

Data was presented as mean (± SD). Paired t-tests were used to ascertain whether between-session differences were significant for the following functional/performance measures: PPO from both isovelocity and isoinertial sprint tests, cadence at PPO for isoinertial test, peak torque for each muscle group for ISO-SINGJT and peak torque for ISO-CYC.

Between-session reliability was measured as by calculating coefficient of variation (CV) (which was calculated by: standard deviation/average) for all the aforementioned measures. CV of PPO was also compared between methods, as well between both experimental sessions using a paired t-test. A one-sample t-test was used to measure any difference between cadence at PPO from the isoinertial test and the cadence from the isovelocity test (i.e. 120 RPM).

Magnitude of peak rmsEMG when produced during both reference tasks as well as when normalised to both sprint tests was carried out by 1) paired t-test 2) Pearson correlation coefficient (r) with ratings as follows: <0.1 trivial, 0.1 – 0.29 small, 0.3 – 0.49 moderate, 0.5 – 0.69 large, 0.7 – 0.89 very large, 0.9 – 1.0 almost perfect.

Between-session reliability when involving absolute peak rmsEMG values were carried out by: 1) a paired t-test was used to assess any significant differences between-sessions 2) Intra-class correlation coefficient (3,1) (ICC) 3) CV. Due to the naturally higher variability of EMG, CV was described by modifying the categories based which has been modified on previous research (Albertus-Kajee et al., 2010). In this case, the categories are as follows: "good" (<10%), "acceptable" (10.0 – 19.9%), "weak" (20.0 – 29.9%) and "very weak" (≥ 30.0%).

One-way ANOVA was used to test for within-group differences in CV for each muscle group between all sprint cycling tests under absolute, ISO-SINGJT and ISO-CYC. A Tukey post-hoc test was used for further analysis if a significant difference was found. The level of significance was set at $P \leq 0.05$.

RESULTS

Functional (Performance) outcomes during Sprint Cycling and Reference Tasks

Functional (performance) outcome measures, specifically PPO during both sprint cycling tests and peak torque values during ISO-SINGJT and ISO-CYC tasks, revealed no significant differences between-sessions (Figure 3 & 4). The isoinertial sprint test produced higher PPO (Figure 4; +5.8 %; p = 0.0151), but the reliability of PPO measured with both tests was similar (Between-session CV for isovelocity and isoinertial were 2.0 vs 3.0 %, respectively; p = 0.1554). For the isoinertial sprint cycling test, cadence at PPO was 122 ±10 RPM (CV of 2.4 %) and thus similar to the optimum cadence for PPO) during the isovelocity sprints (120 RPM; p = 0.575).

ISO-SINGJT peak torque had between session CV values of 3.9 % (knee extensors), 7.1 % (knee flexors), 8.1 % (hip extensors) and 8.2 % (plantar flexors). Whilst ISO-CYC peak cumulative torque had a between-session CV of 5.8 %.

Magnitude and between-session reliability of peak rmsEMG during isovelocity and isoinertial Sprint Tests

No significant differences in peak rmsEMG were seen for respective muscle groups at PPO between both sprint tests. The reliability, between-session CV values, of absolute peak rmsEMG during isovelocity and isoinertial sprint tests were similar for five muscle groups (GL, BF, VL, VM and RF), but for the GM peak rmsEMG during the isoinertial sprints was less reliable than isovelocity (9.0 vs 22.5 %; p = 0.007; Table 1).

Magnitude & Reliability of Peak rmsEMG during Reference Tasks

Peak rmsEMG for ISO-CYC was significantly lower than ISO-SINGJT for 3 out of 6 muscle groups (GL -20% p = 0.0068; BF -34% p = 0.0002; RF -28% p = 0.0154), with similar values for GM (37% p = 0.2431), VM (-4% p = 0.04615) and VL (-18% p = 0.0712; Table 2).

There were moderate to very large relationships between peak rmsEMG assessed with the two reference tasks. With the exception of GM during ISO-SINGJT, no significant differences of peak rmsEMG were seen for either reference tasks between experimental sessions. All muscle groups for both reference tasks showed acceptable levels of between session reliability (i.e. CV between 10 – 20%) with the exception of BF during ISO-SINGJT and RF during ISO-CYC which both exhibit weak (high) CV values. There were no differences in the reliability (CV) of peak rmsEMG for any of the six muscle groups between isovelocity and isoinertial sprint tests (Table 1).

Absolute peak rmsEMG and Normalised EMG (to ISO-SINGJT or ISO-CYC) during Sprint Cycling

There were statistically significant differences for CV of individual muscle groups between sprint cycling tests as determined by one-way ANOVA for GM ($F_{(5, 128)} = 3.994$, $p = 0.002$), BF ($F_{(5,128)} = 5.757$, $p < 0.001$), VL ($F_{(5, 128)} = 3.414$, $p = 0.006$) and RF ($F_{(5, 128)} = 2.934$, $p = 0.015$). Following a Tukey post-hoc test, the significant differences in CV were lower for absolute peak rmsEMG when compared to either ISO-SINGJT and/or ISO-CYC irrespective of the sprint cycling test used. These data are presented in Table 1 and 3.

DISCUSSION

The three principle findings of the experiment were: 1) Peak rmsEMG at PPO during both sprint cycling tests was similar for the six muscle groups assessed; 2) Of the two reference tasks, ISO-SINGJT produced significantly higher peak rmsEMG values for 3 out of 6 muscle groups, but there was similar between-session reliability for both reference tasks; and 3) The reliability of peak rmsEMG during sprint cycling (isovelocity or isoinertial) was not improved by normalisation to either reference task (ISO-SINGJT or ISO-CYC).

Magnitude and Reliability of peak rmsEMG of Isovelocity and Isoinertial Sprint Tests.

From a performance (functional) perspective, PPO was significantly higher in the isoinertial sprint test in comparison to the isovelocity sprint test whilst cadence at PPO was similar for both sprint tests. The parabolic power-cadence and underpinning inverse, linear torque-cadence relationships in sprint cycling implies that the underpinning functional difference of PPO between the two tests is torque production (Driss et al., 2002). There is a well-established relationship with muscle activation with torque/force production (Balshaw et al., 2018; Lippold, 1952). Despite this, no significant difference was measured between peak rmsEMG during PPO of isovelocity and isoinertial sprint cycling methods. This suggests that the difference between tests may be rooted in performance test methodology. For example, isoinertial sprint tests are not performed under fixed, pre-determined cadences and involves accelerating the flywheel (and cranks). This acceleration is neither constant nor linear and the inverse torque-cadence relationship means the torque output at the same point(s) of the each crank cycle is reduced (Figure 2). As no difference was measured between cadence at PPO, it implies that torque when measured by averaging over a revolution reads higher in an isoinertial effort compared to isovelocity efforts. Furthermore, different co-ordination strategies rather than maximal neuromuscular activation that influence PPO between both sprint tests .

The reliability (between session CV) of absolute peak rmsEMG values was similar for isoinertial and isovelocity cycling for 5 (GL, VL, VM, RF and BF) out of 6 muscle groups. Only GM exhibited lower reliability during isoinertial vs isovelocity sprints (Table 1). The conditions might be expected to produce more reliable results by virtue of constant muscle shortening velocity rather than the non-linear acceleration of isoinertial sprints (Figure 2).

Magnitude of Reference Tasks

Three muscle groups (RF, BF and GL) had higher peak rmsEMG during ISO-SINGJT MVCs in comparison to ISO-CYC MVCs, but three other muscles (GM, VL, VM) showed similar values for the two reference tasks. The discrepancy between the references task for some muscles is likely due to the fact that the multiple joint ISO-CYC is limited by torque production of some muscles (i.e. the weakest links in this mechanical situation), which are maximally activated, whilst others muscles are not fully activated in comparison to an isolated single joint task.

Reliability of Reference Tasks

No significant difference was measured between reliability of reference tasks for each respective muscle group. Generally, the reliability for each muscle during either ISO-SINGJT or ISO-CYC was rated as acceptable with the only exceptions being BF ISO-SINGJT and RF ISO-CYC which were rated as weak. None of the between-session reliability measures were rated as good which can be distilled ino three main possibilities: 1) Between-session reliability of the functional outcomes of the reference tasks. With the exception of KE (3.8%), all the reference tasks scored a CV over 5.0% (7 – 8%) indicating poor levels of functional performance between-sessions (Buchheit et al., 2011). This suggests that either or a combination of poor functional task reliability 2) Amplitude cancelation that comes about from the stochastic nature of sEMG with the increase in (voluntary) force production. This is particularly pertinent during MVCs, when motor unit activity is underestimated by sEMG due to the increasing number of simultaneous overlapping positive and negative phases of action potentials resulting in increased variability (Farina et al., 2014) 3) Number of electrodes. This experiment used one electrode per muscle group and though they were averaged over both muscle groups over both legs, it has been suggested that increasing the number of sEMG electrodes over a muscle group might help improve reliability particularly during MVCs (Balshaw et al., 2017), but of course this becomes inherently less practical, more complex, more time consuming, and hence more difficult to deliver in applied situations

Other investigators also attribute the high levels of variability to a various factors including: psychological/motivational factors (Ball and Scurr, 2010; Bamman et al., 1997; Heinonen et al., 1994; Yang and Winter, 1983), synergetic muscle contribution (Miaki et al., 1999) and fatigue onset (Heinonen et al., 1994; Yang and Winter, 1983).

Reliability and Magnitude of Sprint Cycling EMG: normalised (to reference task) vs absolute values

The most notable finding in this part of the experiment was that overall, absolute peak rmsEMG values during sprint cycling had better or at least similar levels of reliability in comparison to normalised EMG values (irrespective of the reference task). Whilst this finding is similar to some previous reaerch (Buckthorpe et al., 2012), it is contrary to recommendations that investigators should use normalising tasks to limit the between-session reliability and improve reliability of EMG during a (performance) task (Kashiwagi et al., 1995; Knutson et al., 1994; Lehman, 2002; Yang and Winter, 1983). The findings from this experiment suggested that the reliability exhibited when using absolute EMG values is at least as good as the reliability shown when using isometric MVCs as reference tasks. This questions the use of isometric MVCs as normalisation procedures when assessing sprint cycling, and indicates that absolute values may be at least as reliable than normalised EMG when wanting to measure changes longitudinally.

In any case, the most plausible reason as why the between-session reliability of peak rmsEMG values of the majority of the muscles during both sprint cycling tests are not significantly better with a normalising task is likely mathematical. The combination of both performance and reference tasks that both exhibit inherent variability. Combining them will exacerbate reliability, rather than improve it and thus, the bias would remain within the EMG amplitude rather than being removed from it.

Limitations and Future experiments

EMG amplitude can be viewed as a basic measure of neural activation. However, there are limitations related to its inferences with neural drive as it has been reported that it may be poorly associated with motor unit recruitment (Del Vecchio et al., 2017) and it is the combination of both neural drive and the properties of the action potentials, without the possibility of distinguishing between the two, it makes EMG amplitude at best, a very crude estimate of neural drive (Farina et al., 2014).

Currently, technological limitations mean that instruments are not advanced enough to measure discharge rates of motor units and recruitment thresholds during dynamic movements. However, highly accurate decomposition sEMG have recently been reported to estimate changes in average conduction velocity with a high degree of accuracy (Del Vecchio et al., 2017) but this is yet to be done in dynamic movements.

In addition, to get a better understanding of muscle activation and recruitment strategies during the crank cycling, inverse dynamics can be used in conjunction with sEMG to understand the contribution (positive or negative) of each muscle group throughout the crank cycle and the magnitude of contribution.

Conclusion

The main findings of this experiment were three-fold: 1) peak rmsEMG values during PPO did not differ between sprint cycling tests and between-session reliability was similar for all muscle groups with the exception of GM which exhibited better reliability for the isovelocity method 2) When peak rmsEMG was compared for both normalising tasks, peak rmsEMG was higher for 3 (GL, BF and RF) out of 6 muscle groups in comparison to ISO-CYC. From a reliability perspective, no difference was seen for any muscle group between both methods. 3) Neither nornalising task improved between-session reliability when compared to absolute rmsEMG values.

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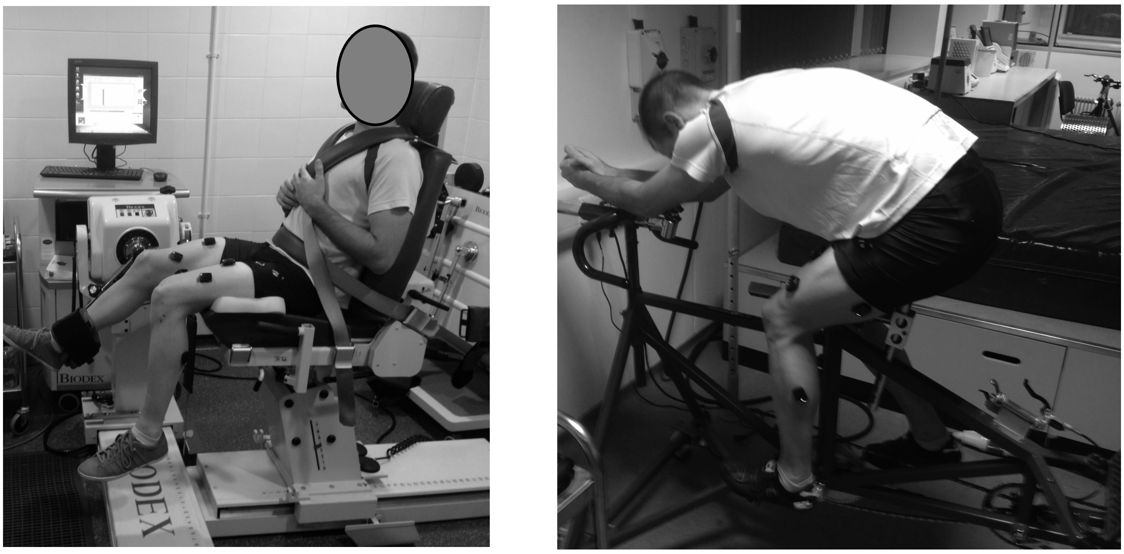

Figure 1: A cyclist performing isometric maximal voluntary contractions using single-joint dynamometry of a knee extensor (left) and isometric cycling (right)

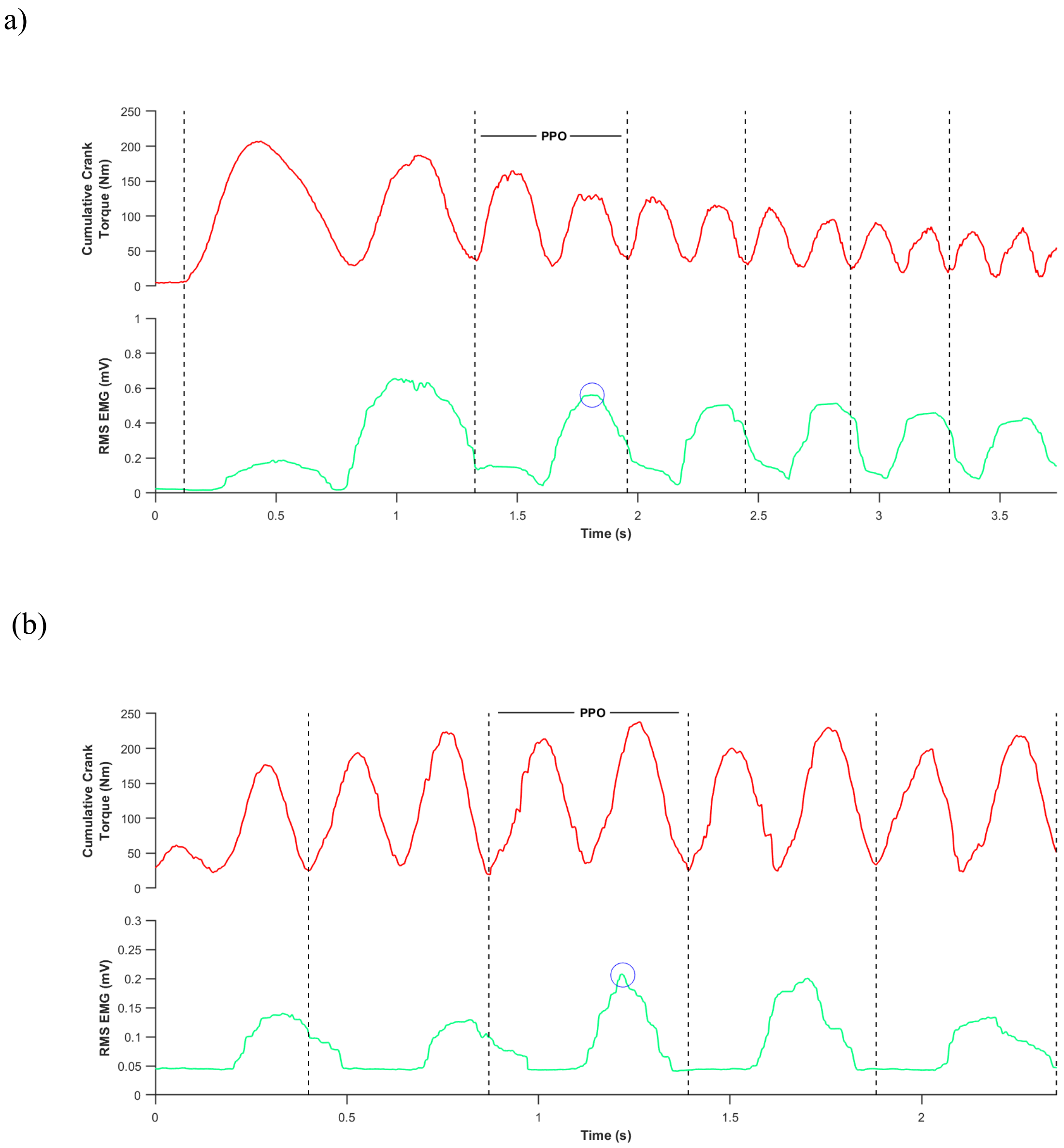

Figure 2: An example of a cyclists torque trace of the (a) isoinertial sprint cycling test and (b) isovelocity sprint cycling tests with the respective RMS EMG trace of the right vastus lateralis. The dotted vertical lines represent each full revolution and time taken to complete each revolution was calculated (i.e. cadence [RPM]). Power (Watts) is expressed over a revolution and calculated as the product of average torque over each full revolution and cadence. The revolution where peak power output (PPO) was achieved was analysed and peak rmsEMG was measured, over the highest 90°sector, from six muscles of each leg.

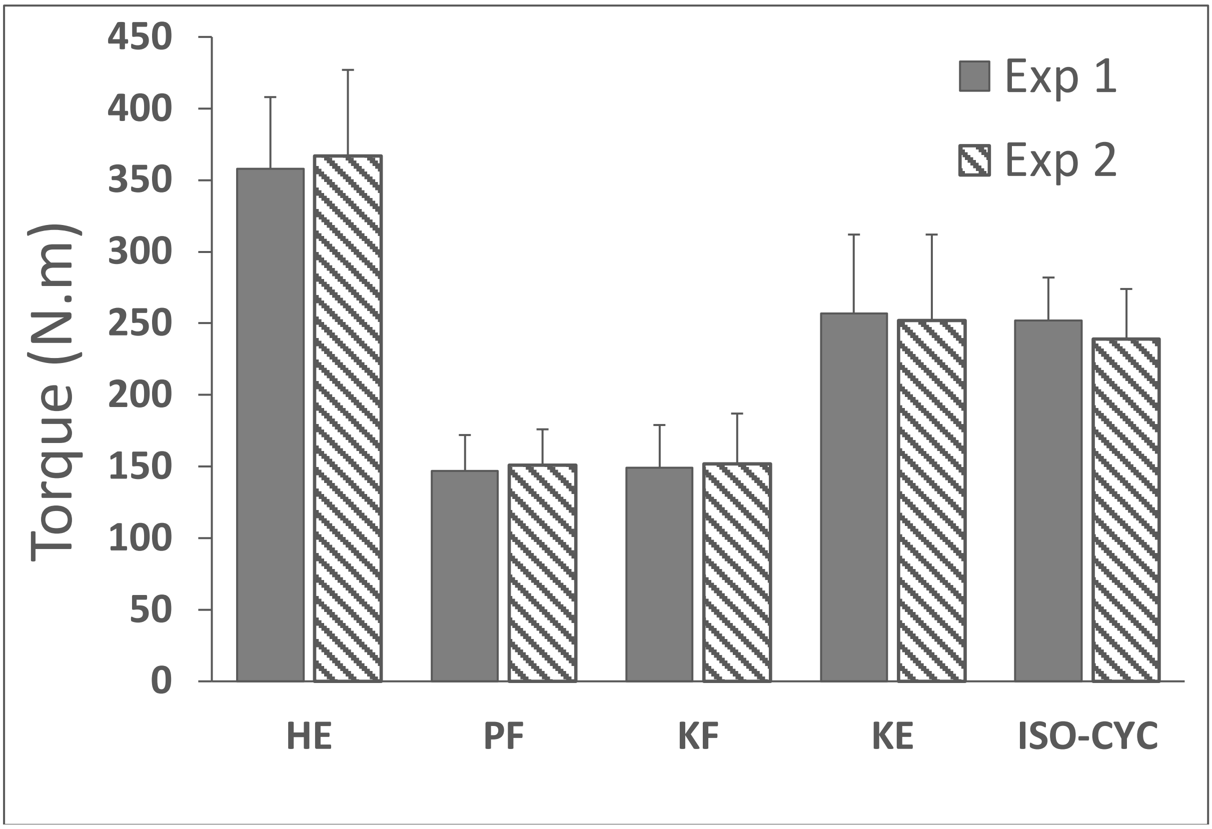

Figure 3: Comparison of peak torque (N.m) production during isometric single joint dynamometry of: knee extensors (KE), knee flexors (KF), hip extensors (HE), plantar flexors (PF) as well as isometric cycling (ISO-CYC) between experimental sessions 1 and 2 (Exp1 & Exp2). No significant difference was seen for any of the tasks between experimental sessions.

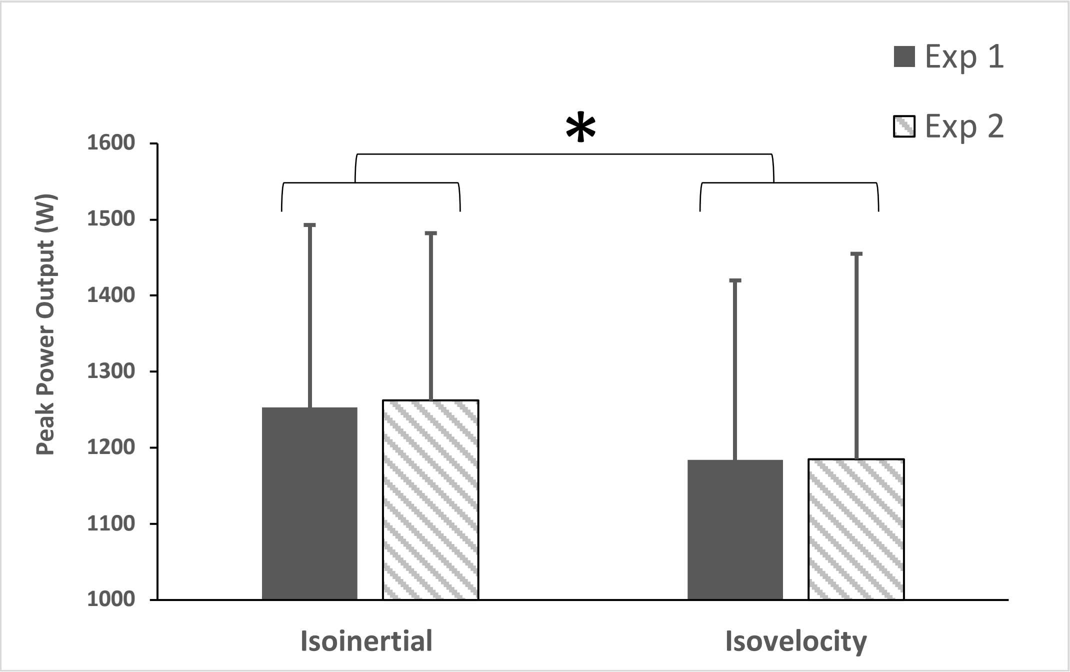

Figure 4: Comparison of between session reliability of peak power output during isoinerital and isovelocity sprint tests. No significant differences were observed for both isovelocity (1184 ± 220 W vs. 1185 ± 270 W; p = 0.8826) and isoinertial (1253 ± 240 W vs. 1262 ± 236 W; p = 0.2399). When the peak power output was compared between sprint tests the difference reached significance (p = 0.0151); * denotes significant difference between isovelocity and isoinertial.

Table 1: Absolute peak rmsEMG values (mV) during experimental sessions 1 (Exp 1) and 2 (Exp 2) of gluteus maximum (GM), gastrocnemius (GL), long head bicep femoris (BF), vastus lateralis (VL), vastus medalis (VM) and rectus femoris (RF) at PPO during isovelocity and isoinertial sprint cycling tests. Paired t-tests were used to identify significant differences between Exp 1 and Exp 2 (Between Session), between isovelocity vs. isoinertial sprint methods for each muscle group, and between session CV (%). Respective CV rating as well as between-session ICC are also presented significance $P < 0.05$; * denotes significant difference between isovelocity and isoinertial

	Exp 1	**Exp 2**	**Between Session**	**Between Session**	**CV Rating**	**Between-Session**	**Average**	**Isovelocity vs Isoinertial**	
	mV	**mV**	**P=**	**CV, %**		**ICC**	**mV**	**Average P=**	**CV P=**
GM									
Isovelocity	0.222 ± 0.169	0.221 ± 0.164	0.940	9.0*	Good	0.98	0.222 ± 0.166	0.656	0.0068
Isoinertial	0.240 ± 0.252	0.221 ± 0.170	0.494	22.5*	Weak	0.92	0.231 ± 0.210		
GL									
Isovelocity	0.291 ± 0.085	0.264 ± 0.089	0.148	13.6	Acceptable	0.80	0.277 ± 0.087	0.839	0.687
Isoinertial	0.294 ± 0.122	0.255 ± 0.088	0.067	15.1	Acceptable	0.84	0.274 ± 0.105		
BF									
Isovelocity	0.162 ± 0.068	0.158 ± 0.074	0.475	6.9	Good	0.97	0.160 ± 0.071	0.587	0.180
Isoinertial	0.162 ± 0.076	0.168 ± 0.067	0.441	11.4	Acceptable	0.94	0.165 ± 0.071		
VL									
Isovelocity	0.436 ± 0.122	0.414 ± 0.127	0.484	15.1	Acceptable	0.67	0.425 ± 0.124	0.718	0.112
Isoinertial	0.397 ± 0.172	0.438 ±0.151	0.245	21.3	Weak	0.78	0.417 ± 0.161		
VM									
Isovelocity	0.641 ± 0.246	0.555 ± 0.199	0.913	21.7	Weak	0.38	0.598 ± 0.223	0.700	0.724
Isoinertial	0.581 ± 0.226	0.438 ± 0.151	0.913	19.0	Acceptable	0.62	0.584 ± 0.213		
RF									
Isovelocity	0.185 ± 0.076	0.199 ± 0.074	0.428	15.0	Acceptable	0.86	0.192 ± 0.075	0.236	0.462
Isoinertial	0.220 ± 0.144	0.200 ± 0.082	0.438	19.3	Acceptable	0.77	0.210 ± 0.113		

Table 2: Absolute peak rmsEMG values (mV) during experimental sessions 1 (Exp 1) and 2 (Exp 2) of gluteus maximum (GM), gastrocnemius (GL), long head bicep femoris (BF), vastus lateralis (VL), vastus medalis (VM) and rectus femoris (RF) during both isometric reference tasks: single-joint dynamometry (ISO-SINGJT) and isometric-cycling (ISO-CYC). Paired t-tests were used to identify significant differences between Exp 1 and Exp 2 (Between-Session), between methods (ISO-SINGJT vs. ISO-CYC for each muscle group) and between session CV (%).Respective CV rating as well as between-session ICC are also presented. The relationship (r) and relationship rating between the two methods is also given; * denotes significant difference between peak rmsEMG between reference tasks; $^{\#}$ denotes significant difference of muscle group between experimental session of same reference task.

	Exp 1	**Exp 2**	**Between Session**	**Between Session**	**CV Rating**	**Between-Session**	**Average**	**ISO-SINGJT vs ISO-CYC**		**Relationship**	**Rating**
	mV	**mV**	**P=**	**CV, %**		**ICC**	**mV**	**Average P=**	**CV P=**	**r**	
GM											
ISO-SINGJT	0.160 ± 0.076	0.199 ± 0.094	$0.0410^{\#}$	15.5	Acceptable	0.92	0.174 ± 0.083	0.2431	0.4851	0.81	Very Large
ISO-CYC	0.265 ± 0.252	0.212 ± 0.108	0.2574	15.5	Acceptable	0.72	0.239 ± 0.078				
GL											
ISO-SINGJT	0.304 ± 0.082	0.295 ± 0.054	0.6956	15.4	Acceptable	0.46	0.299 ± 0.059*	0.0068	0.8747	0.60	Large
ISO-CYC	0.254 ± 0.101	0.226 ± 0.061	0.2135	14.5	Acceptable	0.66	0.240 ± 0.075*				
BF											
ISO-SINGJT	0.233 ± 0.073	0.218 ± 0.056	0.2929	20.8	Weak	0.77	0.225 ± 0.061*	0.0002	0.0570	0.73	Very Large
ISO-CYC	0.145 ± 0.070	0.153 ± 0.070	0.5444	10.7	Acceptable	0.86	0.149 ± 0.067*				
VL											
ISO-SINGJT	0.430 ± 0.201	0.442 ± 0.110	0.7985	15.8	Acceptable	0.50	0.436 ± 0.138	0.0712	0.5562	0.38	Moderate
ISO-CYC	0.378 ± 0.134	0.335 ± 102	0.2180	15.8	Acceptable	0.60	0.356 ± 0.105				
VM											
ISO-SINGJT	0.637 ± 0.213	0.607 ± 0.169	0.6486	11.4	Acceptable	0.33	0.622 ± 0.155	0.4615	0.2099	0.78	Very Large
ISO-CYC	0.619 ± 0.249	0.574 ± 0.157	0.4401	18.6	Acceptable	0.61	0.597 ± 0.184				
RF											
ISO-SINGJT	0.271 ± 0.113	0.272 ± 0.117	0.9628	15.2	Acceptable	0.92	0.272 ± 0.117*	0.0154	0.3778	0.60	Large
ISO-CYC	0.207 ± 0.101	0.185 ± 0.080	0.2009	23.4	Weak	0.85	0.196 ± 0.087*				

Table 3: Reliability of normalised EMG against two reference task (isometric single-joint dynamometer [ISO-SINGJT] and isometric cycling [ISO-CYC]) for the gluteus maximum (GM), gastrocnemius (GL), long head bicep femoris (BF), vastus lateralis (VL), vastus medalis (VM) and rectus femoris (RF) between experimental session 1 (Exp 1) and 2 (Exp 2). p-value of paired t-test, intraclass correlation (ICC), coefficient of variation (CV%) and respective CV% rating; One-way ANOVA was used to measure any significant difference from respective CV% of absolute rmsEMG, normalised ISO-SINGJT and normalised ISO-CYC; † denotes significant difference from CV% of respective absolute peak EMG reliability; # denotes significant difference from respective sprint methods

ISOVELOCITY normalised to ISO-SINGJT (%)

	Exp 1	**Exp2**	**Between Session P=**	**ICC**	**CV%**	**CV% Rating**	**Average**
GM	166 ± 47	154 ± 68	0.582	0.38	24†	Weak	131 ± 42
GL	134 ± 69	115 ± 38	0.275	0.60	22†#	Weak	124 ± 54
BF	99 ± 24	95 ± 40	0.642	0.70	17	Acceptable	97 ± 32
VL	146 ± 58	151 ± 87	0.790	0.78	22	Weak	149 ± 73
VM	167 ± 94	139 ± 56	0.483	0.21	28	Weak	153 ± 75
RF	95 ± 24	121 ± 49	0.153	0.55	18	Acceptable	108 ± 37

ISOINERTIAL normalised to ISO-SINGJT (%)

Exp 1	**Exp 2**	**Between Session P=**	**ICC**	**CV%**	**CV% Rating**	**Average**
162 ± 96	153 ± 68	0.776	0.46	32†	Very weak	157 ± 82
125 ± 54	110 ± 30	0.361	0.47	20#	Weak	118 ± 42
93 ± 29	97 ± 35	0.581	0.81	15	Acceptable	95 ± 32
140 ± 70	162 ± 89	0.261	0.77	28	Weak	151 ± 79
136 ± 54	147 ± 51	0.558	0.48	25	Weak	142 ± 53
107 ± 39	117 ± 37	0.542	0.56	21	Weak	112 ± 38

ISOVELOCITY normalised to ISO-CYC (%)

	Exp 1	**Exp2**	**Between Session P=**	**ICC**	**CV%**	**CV% Rating**	**Average**
GM	128 ± 44	133 ± 40	0.710	0.51	16	Acceptable	179 ± 42
GL	197 ± 129	165 ± 46	0.361	0.46	33†#	Very weak	181 ± 87
BF	173 ± 50	169 ± 34	0.775	0.74	11	Acceptable	171 ± 42
VL	172 ± 67	185 ± 66	0.623	0.30	25	Weak	179 ± 66
VM	192 ± 117	146 ± 65	0.338	0.28	24	Weak	169 ± 91
RF	135 ± 43	139 ± 37	0.764	0.39	16	Acceptable	137 ± 40

ISOINERTIAL normalised to ISO-CYC (%)

Exp 1	**Exp 2**	**Between Session P=**	**ICC**	**CV%**	**CV% Rating**	**Average**
116 ± 45	133 ± 51	0.342	0.51	21	Weak	125 ± 48
197 ± 118	160 ± 41	0.235	0.50	35†#	Very weak	179 ± 80
162 ± 61	179 ±39	0.346	0.53	18	Acceptable	170 ± 50
162 ± 85	200 ± 66	0.158	0.56	30	Very weak	181 ± 75
151 ± 52	154 ± 58	0.891	0.26	26	Weak	153 ± 55
150 ± 58	143 ± 48	0.759	0.16	29	Weak	146 ± 53