Differences in force normalising procedures during submaximal anisometric contractions

Jakob Škarabot[1], Paul Ansdell[1], Callum Brownstein[1], Glyn Howatson[1,2], Stuart Goodall[1] and Rade Durbaba[1]

[1] Faculty of Health and Life Sciences, Northumbria University, Newcastle upon Tyne, England, United Kingdom

[2] Water Research Group, School of Environmental Sciences and Development, Northwest University, Potchefstroom, South Africa

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ABSTRACT

Eccentric contractions are thought to require a unique neural activation strategy. However, due to greater intrinsic force generating capacity of muscle fibres during eccentric contraction, the understanding of neural modulation of different contraction types during submaximal contractions may be impeded by the force normalisation procedure employed. In the present experiment, subjects performed maximal isometric dorsiflexion at shorter (80°), intermediate (90°) and longer (100°) muscle lengths, and maximal concentric and eccentric contractions. Thereafter, submaximal concentric and eccentric contractions were performed normalised to either isometric maximum at 90° (ISO), contraction type specific maximum (CTS) or muscle length specific maximum (MLS). When using ISO or MLS for normalisation, mean submaximal eccentric torque levels were significantly lower when compared to CTS normalisation (11 and 7% lower compared to CTS; p = 0.003 and p = 0.018 for ISO and MLS, respectively). These experimentally observed differences closely matched those expected from the predictive model. During submaximal concentric contraction, mean torque levels were similar between ISO and CTS normalisation with similar discrepancies noted in EMG activity. These findings suggest that normalising to ISO and MLS might not be accurate for assessment and prescription of submaximal eccentric contractions.

Words: 191

INTRODUCTION

Recently, there has been a great deal of interest in the divergent neural modulation of different contraction types, particularly of lengthening/eccentric contractions, which are thought to require a unique activation strategy by the central nervous system (CNS; for a summary, see Duchateau and Enoka, 2016). For example, muscle activity assessed by surface electromyography (EMG) is usually smaller during eccentric compared to isometric and concentric contractions at the same absolute load/force level (Aagaard et al., 2000; Kellis and Baltzopoulos, 1998; Komi et al., 2000; Nardone and Schieppati, 1988). Furthermore, corticospinal and spinal excitability as assessed by motor evoked potentials and either H-reflexes or cervicomedullary evoked potentials, respectively, tend to be lower during maximal and submaximal eccentric contractions (Abbruzzese et al., 1994; Duclay et al., 2014, 2011; Gruber et al., 2009).

Whilst the force-producing capacity of human muscles during eccentric contraction appears to be muscle-dependent (for review see Duchateau and Enoka, 2016), maximal eccentric dorsiflexion force can be substantially greater compared to isometric and/or concentric contractions (~30-50%; Pasquet *et al.*, 2000; Reeves & Narici, 2003; Klass *et al.*, 2007; Duchateau & Enoka, 2016). Thus, due to this greater intrinsic force generating capacity of muscle fibres during eccentric contractions (Edman, 1988; Morgan et al., 2000), submaximal eccentric contractions may not be performed at an appropriate intensity relative to a maximal eccentric contraction if not normalised appropriately, i.e. relative to the specific contraction type. Whilst it seems clear that contraction type specificity should be accounted for when normalising submaximal anisometric contractions, this is not reflected in the existing literature. Indeed, there appear to be vast discrepancies regarding the procedures used for normalising submaximal forces across isometric, eccentric and concentric contractions. For example, anisometric contractions have been normalised relative to an isometric maximal voluntary contraction (MVC; Gruber *et al.*, 2009; Kallio *et al.*, 2010), contraction-type specific MVC (Rice et al., 2015; Tallent et al., 2012) or muscle-length specific MVC (Duclay et al., 2014; Pasquet et al., 2006). Appropriate normalisation is of particular significance when stimulations are performed to assess neuronal behaviour, such as corticospinal modulation of different contraction types (e.g. Gruber *et al.*, 2009; Tallent *et al.*, 2013; Duclay *et al.*, 2014). Specifically, inappropriate normalisation may result in different contraction types to be at different levels of contraction intensity-stimulus response curve of various responses (Capaday and Stein, 1987; Goodall et al., 2009; Matthews, 1986; Oya et al., 2008; Weavil et al., 2015), which could impede the understanding of the proposed divergent neurophysiological response. Furthermore, appropriate normalisation is of vital importance when assessing steadiness of force-matching tasks as the standard deviation and the coefficient of variation of force/torque production (procedures commonly used to quantify force steadiness) are dependent on relative intensity of force/torque production (Enoka et al., 2003).

Given the discrepancy of normalising procedures described in the literature, the purpose of this study was to directly assess and compare the influence of different normalising procedures previously used under the same overall experimental conditions (i.e. the same population, dynamometer setup, contraction velocity, posture and joint positioning) in torque-matching tasks on mean torque and EMG activity during submaximal anisometric contractions with the aim of informing practice and design of future studies. To visualise discrepancies and inform a hypothesis, a predictive model based on experimentally acquired different types of MVC was constructed. Based on that, it was hypothesised that the experimental data will show that normalisation to an isometric MVC or muscle-length specific MVC results in significantly lower submaximal torques and EMG activity compared to when normalised to contraction-type specific MVC.

METHODS

Participants

Seven young, recreationally active (i.e. meeting the recommended activity guidelines of World Health Organisation, 2010) men (age 25 ± 4 years; stature 179 ± 7 cm, mass 81 ± 10 kg) participated in the study. All participants were free from neurological illness or musculoskeletal injury. Written informed consent was obtained prior to participation. The study received institutional approval and conformed to the *Declaration of Helsinki*.

Torque and EMG procedures

Dorsiflexors were chosen as an experimental model due to their unique behaviour during lengthening contractions. Specifically, whilst not all human muscles may exhibit greater force capacity during eccentric contractions compared to other contractions types (for review see Duchateau and Enoka, 2016), dorsiflexors have consistently demonstrated significantly greater eccentric force (Pasquet *et al.*, 2000; Reeves & Narici, 2003; Klass *et al.*, 2007; Duchateau & Enoka, 2016), making them a superior model compared to other muscles to study discrepancies in force production across different contraction types. Dorsiflexion torque from the right ankle was recorded on an isokinetic dynamometer (Cybex, Lumex Inc., USA) with hip and knee angles set at 90° flexion. For anisometric contractions, range-of-motion (ROM) moved from 10° dorsiflexion to 10° plantarflexion, with anatomical zero set with the ankle joint at 90°. Contraction velocity was kept at $5°\cdot s^{-1}$. Participants performed MVCs under the following conditions: isometric contractions with the ankle at 80, 90 and 100° (corresponding to shorter, intermediate and longer muscle lengths, respectively) and anisometric contractions, i.e. isokinetic shortening and lengthening. For isometric contractions, participants were instructed to increase torque to their maximal level and maintain it for 4 s. During anisometric contractions, torque was produced during the 4-second movement of the dynamometer. Surface EMG was recorded using bipolar self-adhesive electrodes (8-mm diameter, 20-mm inter-electrode distance; Kendall 1041PTS, Tyco Healthcare Group, USA) placed on tibialis anterior muscle belly according to SENIAM recommendations at one-third of the length between the tip of the fibula and the tip of the medial malleolus in the direction of this line (Hermens et al., 2000), with a ground electrode placed on the patella. Prior to placement of electrodes, the recording site was shaved, abraded with preparation gel and wiped clean with an alcohol swab to ensure appropriate electrode resistance ($< 2k\Omega$). The EMG signal was amplified (×1000) and band pass filtered (3-1000 Hz; Neurolog System, Digitimer Ltd, UK). Torque and EMG signals were digitised (5 kHz; CED 1401, CED, UK), acquired and analysed off line (Spike2, v8, CED, UK).

Experimental protocol

Participants attended the laboratory to complete a single measurement session. After initial warm-up involving individually estimated 50% submaximal isometric contractions, participants performed isometric MVCs at the pre-defined angles. Two MVCs per contraction type were performed with a rest period of 60 s between each to avoid fatigue. The greatest instantaneous value of the two attempts was recorded as the MVC. This was followed by the first part of the experiment, which involved concentric and eccentric contractions in a randomized order, set to a level equal to 50% isometric MVC at the intermediate muscle length (isometric normalisation; ISO). The second part of the experiment involved obtaining anisometric MVCs (randomised order, two trials per contraction type, 60 s rest) followed by anisometric contractions at 50% of contraction-type specific MVC (contraction-type specific normalisation; CTS). During ISO and CTS trials, participants were instructed to increase their torque level to the target torque and attempt to follow the target line as closely as possible throughout the 4-second contraction (visual feedback was provided through a monitor displaying the target torque). Finally, the muscle length-specific (MLS) submaximal anisometric contractions were performed. An example of a lengthening contraction during MLS is depicted in Figure 1. Lengthening contractions were initiated by matching the torque level with the line representing 50% of isometric MVC at shorter muscle length (Figure 1A). As muscle length increased, participants resisted the motion of the dynamometer reaching the line representing 50% of isometric MVC at an intermediate muscle length situated at the mid-point in ROM (Figure 1B), and finished the contraction by matching the line signifying 50% of isometric MVC at a longer muscle length (Figure 1C). For shortening contractions, the order of torque matching was reversed. This protocol is similar to that previously described by Pasquet *et al.* (2006). For each condition and torque level, participants were given at least 10 practice trials, as it has been reported that fluctuations in torque production plateau following such practice (Hortobágyi et al., 2001). Subsequently, experimental trials were performed of which four successful trials per condition, contraction type and contraction level were used and averaged for all measures (ISO, CTS, and MLS). A trial was deemed successful if participants produced a steady torque for 4 seconds (ISO, CTS) and produced a parabolic-like shape of torque covering the three time points at appropriate times (MLS). Due to the practice trials executed beforehand, no more than five experimental trials were needed for all participants. A minimum of 30 s rest was given between each contraction to avoid fatigue.

[Insert Figure 1]

Data analysis

Maximal torques and corresponding root mean square EMG activity (RMS EMG) were analysed first. For the purpose of better representation and visualisation of conceptual issues, the mean MVC values of the sample were then used to construct a predictive model for submaximal contractions using different normalising procedures. This was done as it allows the assessment of what torque levels are expected to emerge from different normalisation procedures which might be different to experimental values due to inaccurate torque production, particularly during eccentric contractions (Hortobágyi et al., 2001). In the predictive model, for CTS and ISO normalization, a single value of mean percentage torque for concentric and eccentric contractions was calculated. For MLS normalization, the percentage of torque at shorter, intermediate and longer muscle lengths and the percentage of mean torque production were calculated. Whilst it is recognised that this type of normalisation will result in a parabolic torque production as per torque-angle relationship (Billot et al., 2011), for simplicity and the purposes of illustration, the percentage of mean torque production during MLS was computed assuming separate linear relationships between the shorter and intermediate lengths and between the intermediate and longer muscle lengths. For all submaximal contractions in the experiment, data from 4 successful attempts for each contraction type and intensity were analysed. Since the aim of the study was to compare the so-called ‘torque-matching’ task (e.g. Rice et al., 2015) across different contraction types, to allow for a valid comparison between them only the last 3.2 s of each trial was used to calculate the mean torque and RMS. The first 0.8 s of each trial was excluded from analysis since torque had yet to reach the target line in most attempts. This exclusion time removed any issue that the acceleration phase at the start of the movement might be analysed as this was typically restricted to the initial 0.05 s of movement. Also, the deceleration component at the end of motion was not analysed as it was found to start just after the end point of the 3.2 s analysis period. As such, the acceleration and deceleration phases of motion were ignored, allowing for a ‘true’ torque-matching task comparison. Mean torque is presented both in absolute and relative values, i.e. normalised to CTS MVC. The calculated RMS EMG activity was normalized to RMS EMG obtained during CTS MVC.

Statistical analysis

Data are presented as mean ± standard deviation, unless stated otherwise. All analyses were performed using SPSS package (v20, SPSS Inc., USA). Statistical significance was set at an alpha level of 0.05. Normality of the data was assessed using Shapiro-Wilks test. Sphericity was assessed using Mauchly’s test, and if violated, a Greenhouse-Geisser correction was employed. One-way repeated measures ANOVA was used to analyse the differences between different types of MVC. A two-way (3×2) ANOVA with repeated measures design was employed to analyse differences between different normalising procedures (ISO, CTS, MLS) and contraction types (concentric, eccentric). If significant F-values were found, the post hoc pairwise comparison was performed with the Fisher least significant difference test. Partial eta squared (η_p^2) was calculated to estimate effect sizes associated with main effects of ANOVA. To allow for a more nuanced interpretation of the data, Cohen’s d_z effect-sizes were calculated for significant pairwise comparisons. Cohen’s d_z was calculated as the ratio of mean difference and standard deviation of differences, which slightly differs from traditional Cohen’s *d* calculation in that it is better suited for within-subject, rather than traditional between-subject differences (Becker, 1988; Lakens, 2013; Smith and Beretvas, 2009). One sample t-test was used to assess disparity of relative mean torque compared to the CTS MVC and the predictive model.

RESULTS

Maximal torque production and the associated RMS EMG

Maximal torque showed contraction type dependency ($F_{2.0,\ 11.7} = 28.8$, $p < 0.001$, $\eta_p^2 = 0.8$; Table 1). Post-hoc analysis showed, maximal eccentric torque was greater than any maximal isometric torque value ($p < 0.005$, d_z range = 1.2 – 2.2) or concentric maximal torque ($p = 0.001$, $d_z = 1.3$). Comparison between concentric and isometric MVC values showed a difference to shorter muscle length only ($p = 0.005$; $d_z = 1.3$). Across isometric MVC values, longer length was significantly greater compared to either intermediate ($p = 0.011$, $d_z = 0.7$) or shorter muscle length ($p = 0.001$, $d_z = 1.6$) and intermediate length was greater than shorter length ($p = 0.047$, $d_z = 0.9$). Contraction type had no effect on maximal RMS EMG values ($F_{1.3,\ 7.7} = 1.3$, $p = 0.306$, $\eta_p^2 = 0.2$).

[Insert Table 1]

Predictive model

A predictive model was constructed so that ISO and MLS are presented relative to CTS (Figure 2). For concentric contractions, mean torque level during ISO normalization is expected to be very similar compared to CTS (3% difference, Figure 2A). With MLS normalization, whilst the mean concentric torque level is expected to be very similar compared to CTS (4% difference; Figure 2B), during the latter part of the contraction the torque level is smaller than expected, being 12% less at the point of cessation. For eccentric contractions, all predicted percentage torque levels for either ISO or MLS normalization are lower than expected for CTS normalization (Figure 2C and 2D).

[Insert Figure 2]

Absolute mean torque and RMS EMG during submaximal contractions

There was a significant normalising procedure × contraction type interaction for mean torque during submaximal contractions ($F_{2,12} = 8.3$, $p = 0.005$, $\eta_p^2 = 0.6$). Mean eccentric torque was greater compared to concentric regardless of the normalising procedure employed ($p < 0.03$ for all, d_z range = 0.6 – 1.7; Figure 3 top row). Furthermore, CTS mean eccentric torque was greater compared to ISO ($p = 0.003$, $d_z = 1.4$) or MLS ($p = 0.018$, $d_z = 1.0$). There was a significant normalising procedure × contraction type interaction for RMS EMG ($F_{2,12} = 4.5$, $p = 0.035$, $\eta_p^2 = 0.4$). RMS EMG was greater during concentric compared to eccentric contraction regardless of the normalising procedure employed ($p \leq 0.001$ for all, d_z range = 1.9 – 3.8, Figure 3 bottom row). RMS EMG activity was greater during eccentric contraction for CTS compared to ISO ($p = 0.021$, $d_z = 0.9$) or MLS ($p = 0.025$, $d_z = 1.0$).

[Insert Figure 3]

Relative mean torque and the associated torque accuracy

With CTS normalisation, individuals were able to match the expected/predicted 50% torque level for eccentric contractions. However, relative mean concentric torque levels were significantly lower compared to the 50% predicted value ($p = 0.002$; Figure 3-A2). Mean percentage torque levels for concentric and eccentric contractions with ISO normalisation were significantly smaller when compared to CTS normalization values ($p = 0.005$ and $p < 0.001$, respectively; Figure 3-B2), but not different from the predictive values. Relative mean eccentric torque level during MLS normalization was significantly smaller as compared to

CTS normalization (p = 0.011), but significantly greater when compared to the predictive model (p = 0.009; Figure 3-C2).

DISCUSSION

The purpose of this study was to present and assess the disparities in mean toque production and associated EMG activity during anisometric submaximal contractions arising from different normalising procedures that have been previously used in the literature, with the aim of informing future practice. The main finding of the present study is that normalising to ISO and MLS is not an accurate approach when performing submaximal *eccentric* contractions since these two types of normalisation were characterised by significant discrepancy relative to CTS. However, the method of normalisation is less relevant during submaximal *concentric* contractions due to the difference relative to CTS normalisation being small.

Maximal dorsiflexion eccentric torque was found to be ~27 and ~36% greater compared to concentric and isometric at intermediate length, respectively, a finding comparable to previous work (Klass et al., 2007; Reeves and Narici, 2003). As a result, with ISO normalization, submaximal eccentric torque was predicted to be 13% lower compared to CTS normalisation, which was supported by our experimental findings where the mean observed difference was 11%. Thus, submaximal eccentric contractions with ISO normalisation cannot be construed as an accurate submaximal representation of this specific contraction type when comparing contraction types. From a perspective of mechanical output, normalising different anisometric contractions to a constant value, as is the case with ISO normalisation, is similar to lifting and lowering an arbitrary absolute load. For such a task, the associated conceptual methodological issues have been highlighted previously (Duchateau and Enoka, 2016). Specifically, due to aforementioned greater capacity to produce force during eccentric contractions, less motor unit activity is needed to produce the same absolute force. This is supported in the present experiment by lower EMG activity observed during submaximal eccentric contractions with ISO normalization, compared to CTS. This finding could have a significant confounding effect when neural behaviour of eccentric contractions is assessed via stimulation techniques, such that with ISO and MLS normalisation, eccentric contractions at a given percentage of maximum will be at a different level of the contraction type-stimulus response curve relative to concentric and isometric contractions (Capaday and Stein, 1987; Goodall et al., 2009; Matthews, 1986; Oya et al., 2008; Weavil et al., 2015). Furthermore, submaximal eccentric contractions derived from ISO or MLS normalisation might exhibit lower and higher standard deviation and coefficient variation of force, respectively (Enoka et al., 2003), resulting in inaccurate assessment of steadiness.

Due to similarity in peak torque obtained during concentric and intermediate length isometric, the difference between CTS and ISO normalisation procedures is less profound. Indeed, based on the predictive model this difference is 3% and experimental data supports this, with a ~1% difference. Therefore, if investigations are only concerned with submaximal concentric contractions, normalisation can be performed to CTS MVC or isometric MVC at either intermediate or longer muscle lengths. The latter is valid as peak torque during anisometric contractions usually occurs at longer muscle lengths as per torque-angle relationship (Billot et al., 2011).

In an attempt to assess a similar change in torque during anisometric contractions, some researchers have normalised submaximal contractions to MLS maximal isometric contraction (Duclay et al., 2014; Pasquet et al., 2006). Theoretically, this should allow torque production to match the torque-angle curve of the muscle. However, this procedure does not appear to give a valid submaximal representative of a given anisometric contraction type for several reasons. Firstly, the capacity of a muscle to produce torque throughout ROM is unlikely to be linear. This is highlighted in the torque trace presented in our theoretical model, using a 3-point target normalisation rather than a 2-point one used previously (Duclay et al., 2014; Pasquet et al., 2006). Secondly, even though the first half of the contraction, and the mean torque production during concentric MLS appear to be close to CTS, the latter part of the contraction will eventually result in 12% smaller torque level, as per the predictive model (Figure 2). However, if submaximal torque production is assessed in the first portion of the contraction or stimulations are performed at anatomical zero (e.g. Duclay et al., 2014), then MLS normalisation could still be considered accurate during *concentric* contractions only. Thirdly, during eccentric contractions, the starting and finishing point of a contraction were predicted to be 20 and 9% smaller, respectively, compared to CTS, resulting in 14% smaller mean torque production throughout ROM. Our experimental findings showed that maximal torque during longer and shorter muscle length fell significantly short of maximal torque produced during eccentric and concentric contractions in the present study. This was then reflected in submaximal mean torque production and the associated EMG activity insofar as mean eccentric torque was significantly smaller compared to CTS, but still greater than predicted with our theoretical model, possibly due to overshooting the target torque (see below). Furthermore, RMS EMG activity during MLS was significantly smaller, compared to submaximal eccentric contraction using CTS. Theoretically, basing MLS normalisation on each instant of ROM should allow a complete match of the torque-angle curve, thereby making it more representative of a specific contraction type throughout the whole ROM. However, such a task might require a great degree of learning to follow a significant curvilinear torque profile rather than a steady torque level, potentially rendering it less practical. Since the aim of this study was to compare existing normalisation procedures used in the literature directly, a procedure whereby normalisation is performed at each instant of ROM was not investigated, but future studies should assess its effect and practicality.

In theory, when ISO and MLS normalisation are performed, mean torque during concentric and eccentric contractions should be similar, which is not accurate relative to their respective maximums due to greater force capacity during eccentric contractions. However, we show that mean torque production is greater during eccentric contraction during these two procedures, which likely stems from impaired torque accuracy. Indeed, eccentric contractions during MLS were characterised by significant overshooting of the target torque (7% greater mean torque production than predicted), which is reportedly a feature of eccentric contractions (Hortobágyi et al., 2001). During MLS, impaired torque accuracy is likely to be even more apparent due to the target not being a constant line.

Whilst CTS normalisation appears to be the most ecologically valid normalising procedure, it is not without its limitations. Because the capacity of muscle torque is dependent on muscle length, maximal concentric and eccentric contractions are characterised by descending and ascending torque profiles, respectively. When submaximal contractions are performed, and a constant target torque is set, it is based on the peak value achieved during maximal contractions. This results in increasing and decreasing effort required to produce a given torque level throughout ROM during submaximal concentric and eccentric contractions, respectively. Differences in effort could potentially influence the associated EMG activity as when the muscle is at a shorter length greater neural drive is required to maintain the same absolute torque output. Regardless, this could be considered a representative of a real-world scenario. For example, when dorsiflexors are used to control foot drop during heel strike (Byrne et al., 2007), muscle length varies but the force produced needs to be relatively constant to prevent tripping.

In conclusion, the findings of the present study suggest that normalising to ISO and MLS is not an accurate approach for assessment and prescription of submaximal *eccentric* contractions based on the predictive model and the experimental data showing both ISO and

MLS normalisation resulted in significantly lower mean torque during submaximal eccentric contractions. As such, future research, particularly in the area of assessment of neural behaviour of submaximal eccentric contraction should carefully consider the appropriate normalising procedure, with CTS likely being the most accurate approach. For assessment and prescription of submaximal *concentric* contractions, normalization to CTS MVC or isometric MVC at either intermediate or longer muscle length may be accurate and used interchangeably.

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Table 1. Torque and RMS EMG activity during different maximal contractions.

	Isometric			*Anisometric*	
	Shorter	Intermediate	Longer	Concentric	Eccentric
MVC (N·m)	37.7 ± 7.7$^{\#}$	46.4 ± 6.3	51.9 ± 4.3§	49.7 ± 5.7	63.1 ± 8.3*
RMS (mV)	0.49 ± 0.12	0.53 ± 0.13	0.46 ± 0.10	0.49 ± 0.09	0. 49 ± 0.10

MVC = maximal voluntary contraction torque; RMS = root mean square EMG activity. $^{*}p < 0.005$ *compared to all others;* $^{\S}p < 0.015$ *compared to eccentric, intermediate length isometric and shorter length isometric;* $^{\#}p < 0.05$ *compared to all others.*

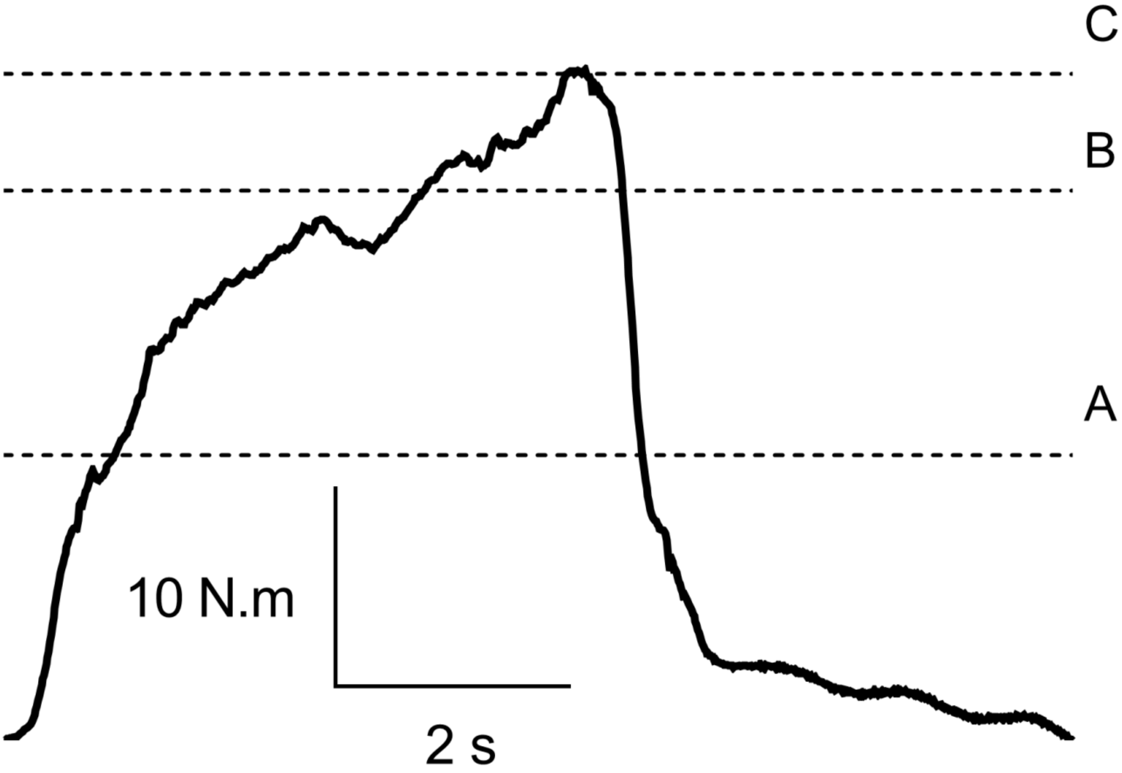
Figure legends.

Figure 1. An example of submaximal eccentric muscle length-specific contraction. The motor of the device moved once participant reached the line representing 50% of the shorter muscle length isometric MVC (A). Thereafter, participants were instructed to resist the motion of the device reaching the line representing 50% of the intermediate muscle length isometric MVC about half-way throughout the range-of-motion (B), and finishing the contraction at the line representing 50% of the longer muscle length isometric MVC (C).

Figure 2. Predictive model of submaximal concentric (A, B) and eccentric (C, D) contractions based on experimental mean MVC values. Dotted lines represent submaximal contraction for CTS normalisation, whereas solid lines represent submaximal contractions for ISO (A, C) or MLS normalisation (B, D). Percentages of torque production, relative to CTS, are depicted in all panels. For A and C, values are shown in the middle as torque production is constant. For MLS (B, D), values are presented at the onset, the midpoint and the cessation of the contraction, with mean percentage torque presented in the brackets.

Figure 3. Torque and EMG activity during submaximal concentric and eccentric contractions. CTS, ISO and MLS normalisation relate to columns A, B & C respectively. Row 1 – Mean torque. Row 2 – Mean torque relative to CTS MVC. Row 3 – Mean RMS EMG relative to CTS RMS EMG. $^{*}p < 0.030$ compared to concentric; $^{\#}p \leq 0.025$ compared to when normalised to isometric MVC and muscle length specific isometric MVC; $^{\dagger}p < 0.015$ compared to 50% contraction-type specific maximum; $^{\S}p < 0.010$ compared to the predictive model.

Figure 1



480 Figure 2

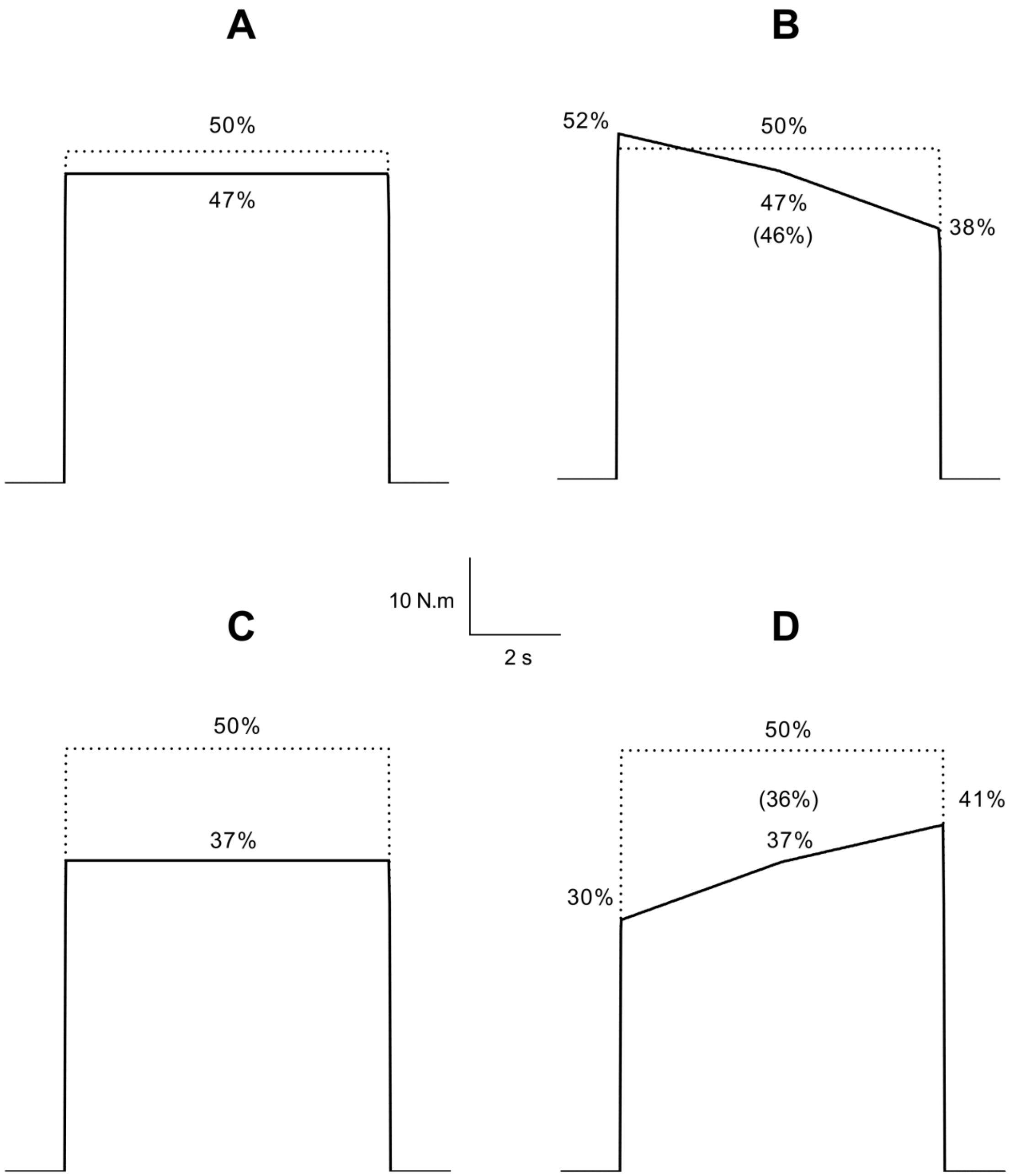


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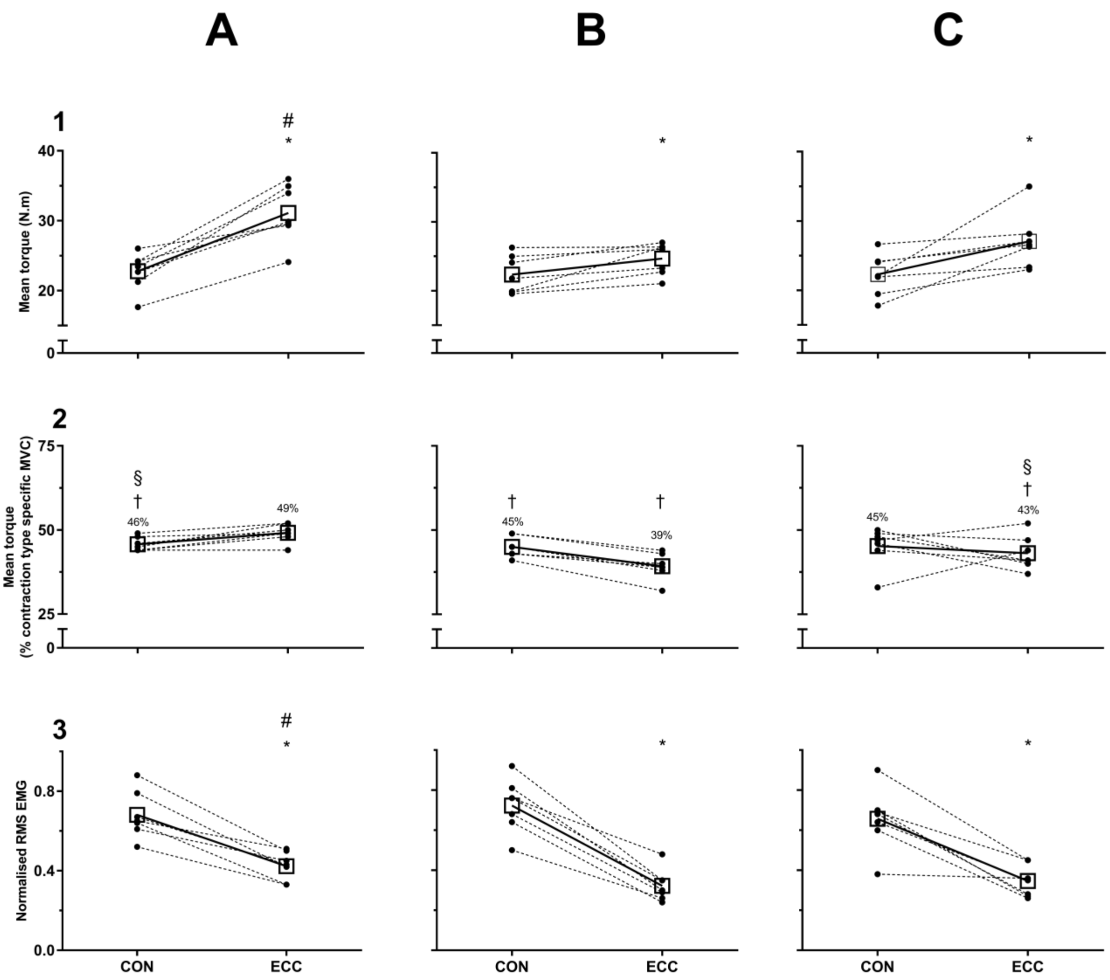
Figure 3


A
B
C
1
Mean torque (N.m)
40
30
20
0
#
*
*
*
2
Mean torque
(% contraction type specific MVC)
75
50
25
0
§
†
46%
49%
†
45%
†
39%
45%
§
†
43%
3
Normalised RMS EMG
0.8
0.4
0.0
#
*
*
*
CON
ECC
CON
ECC
CON
ECC