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The Influence of Verbal Instruction on Measurement Reliability and Explosive Neuromuscular Performance of the Knee Extensors

by
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The current study aimed to examine the effect of verbal instruction on explosive force production and between-session measurement reliability during maximal voluntary contractions of knee extensors. Following familiarization, 20 healthy males performed 3 maximal contractions with a "hard-and-fast" instruction and 3 maximal contractions with a "fast" instruction during 2 test-retest sessions. Knee extension maximal voluntary force (F_{max}) and the maximal rate of force development (RFD_{max}) were measured. Maximal electromechanical delay (EMD_{max}), and the maximal rate of muscle activation (RMA_{max}) of quadriceps muscles were determined. No significant effect of instruction was observed on F_{max} ($p > 0.05$). The RFD_{max} and RMA_{max} were significantly higher with the "fast" compared to the "hard-and-fast" instruction (36.07%, ES = 1.99 and 37.24%, ES = 0.92, respectively), whereas EMD_{max} was significantly lower with the "fast" instruction compared to the "hard-and-fast" instruction (-3.79%, ES = - 0.29). No significant differences between test and retest measurements were found ($p < 0.05$). However, the reliability of the RFD_{max} was higher with the fast instruction compared to the hard-and-fast instruction (CV: 7.3 vs. 16.2%; ICC: 0.84 vs. 0.56). Besides, the RFD_{max} was associated with the RMA_{max} and EMD_{max} with a significant effect of instruction. Data showed that the instruction given prior contracting muscle affected explosive force production and associated neuromuscular variables. As a result, the "fast" instruction may be preferred in the assessment of explosive force capacity of skeletal muscle during maximal efforts.

Key words: maximal force, force development, electromyography, neuromuscular performance.

Introduction

The explosive contraction of skeletal muscles is fundamental in many sports activities such as sprinting, jumping, throwing and cycling. Skeletal muscle function can be assessed with the use of dynamic or isometric voluntary contraction protocols. Of particular importance when assessing the maximal voluntary contraction (MVC) two attributes are generally determined: the subject's maximal force generating capacity, i.e., maximal voluntary force (F_{max}), and the maximal rate at which force can be developed, i.e., the maximal rate of force development (RFD_{max}) (Maffiuletti et al., 2016).

Some authors have reported a strong positive relationship between the RFD_{max} and F_{max} achieved during MVCs (Bellumori et al., 2011; Van Cutsem et al., 1998; Gołaś et al., 2016). Other research studies, however, have shown that the verbal instruction given by the investigator influenced RFD_{max} measurement (Bozic et al., 2012; Christ et al., 1993; Holtermann et al., 2007; Sahaly et al., 2001; Stastny et al., 2015). For instance, the recorded RFD_{max} differed when subjects were asked to exert muscle force in a "fast" or in a "hard-and-fast" fashion. Indeed, the RFD_{max} was significantly higher when subjects were instructed to exert muscle force in a "rapid"

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fashion with no concern for F_{max} than when they were asked to exert muscle force in a "strong and rapid" fashion (Sahaly et al., 2001, 2003).

Explosive force production is a by-product of a neural drive from the central nervous system and intrinsic muscle properties (Johnson et al., 2015). Consequently, the rate of muscle activation (RMA), which defines the slope of the EMG activity-time curve in the earlier phase of force development (Inglis et al., 2013; Mitchell et al., 2011), and the electromechanical delay (EMD), the time between muscle activation and muscle force generation (Zhou et al., 1995, 1996), are important descriptors of neuromuscular performance during MVCs. These two attributes may be affected by the instruction when assessing subject's explosive force generating capacity.

The literature revealed conflicting findings regarding the relevance of the relationship between isometric testing and dynamic performance capacity (Juneja et al., 2012). One possible rationale for the conflicting relationship between isometric force assessment and dynamic activities or dynamic force measurement results could be related to the effect of instruction on the reliability of the measurements. The authors know of no study that has examined the impact of the instruction on the reliability of explosive force production and associated neuromuscular variables. Such observations may enhance our understanding regarding neuromuscular strategies during MVCs and provide important implications for neuromuscular testing and training regimens with practical considerations for both athletes and practitioners. Thus, we designed the current study aiming to examine the effect of the instruction on the reliability of neuromuscular variables during MVCs of knee extensors. Additionally, the impact of the instruction on the relationships between the RFD_{max} and neuronal variables was evaluated to determine which instructions induced the greatest outcome.

Methods

Participants

Twenty healthy males were recruited to participate in this study. The participants' mean (± standard deviation) age, body height and body mass were 23.45 ± 1.99 years, 1.83 ± 0.05 m and 77.79 ± 4.85 kg, respectively. All participants were physically active and regularly engaged in aerobic and resistance exercises as part of their training regimens. The participants had no (i) current injury to the back, upper or lower limbs; (ii) orthopedic lower limb injury in the past six months; or (iii) history of neurological disorders or lower limb ligament surgery. Each participant completed an informed written consent form before in the commencement of the study. The study was approved by the Institutional Review Board of the Rehabilitation Centre and conducted in accordance with the Declaration of Helsinki.

Experimental procedures

We designed a cross sectional study in order to assess the effects of 2 different verbal instructions on the reliability of the various variables related to explosive force production during the MVC of knee extensors. A week prior to the experimental period, all of the participants visited the laboratory to familiarize themselves with the testing apparatus and specific requirements, performing several MVCs with different instructions. Then, the participant performed two experimental sessions at the same time of day to avoid the effects of diurnal variations (Jaafar and Lajili, 2018), two-seven days apart. All testing was performed in a room at constant temperature and relative humidity (mean ± SD: 22 ± 0.1°C and 40 ± 0.4%, respectively) in order to minimize potential effects of ambient temperature changes on neuromuscular performance (Bell, 1993). The participants were instructed to adhere to an identical pretest protocol: to refrain from intense physical activity for 48 hours before the experimental session and to maintain their usual sleeping habits on the night preceding each experimental session. The participants performed a specific light warm-up consisting of five minutes of cycling on a cycle ergometer (Monark 828E, Vansbro, Sweden).

Electrode Placement

Recording electrodes were placed according to the European recommendations for surface EMG (Hermens et al., 2000). The skin under the electrode was shaved to remove hair and dead cells, treated with abrasive gel and cleaned with isopropyl alcohol to achieve inter-electrode impedance below 2 kΩ. The EMG signals were collected by a pair of adhesive bipolar surface electrodes (FIAB, Florence, Italy)

attached to the dominant leg. The electrodes were fixed lengthwise on the skin and parallel to the direction of the muscle fibers at an inter-electrode distance of 20 mm. The electrodes were placed at approximately 2/3 of the distance between the anterior superior iliac spin and the lateral aspect of the patella for the vastus lateralis, at approximately 4/5 of the distance between the medial gap of the knee joint and the anterior superior iliac spine for the vastus medialis, and at 1/2 of the distance between the anterior superior iliac spine and the superior border of the patella for the rectus femoris (Hermens et al., 2000). The electrode placement sites were determined visually during a resisted isometric contraction, and were marked with an indelible felt-tip pen to allow repeated measurements from the same muscle area in the subsequent session. The reference electrode was placed over the lateral right malleolus.

Apparatus and testing position

The participant was seated on a padded chair designed for isometric knee extension force testing (Kin-Com, Chattanooga, TN, USA). The participant's thighs, pelvis, and trunk were pressed tightly against the chair using 5-cm wide non-elastic straps to minimize any extraneous movement of the muscle group of interest. A calibrated strain-gauge force transducer (Interface Inc., Scottsdale, AZ, USA) was coupled to the participant's dominant leg by a non-elastic band positioned just above the lateral malleolus. The knee and hip joints were fixed at 90°. The rigid interface between the transducer and the leg provided virtual isometric conditions for exerting the knee extensor forces.

Instruction protocol

During each experimental session, the participants performed one set of three MVCs with the "hard-and-fast" instruction and one set of three MVCs with the "fast" instruction in randomized order (Sahaly et al., 2001). The MVCs were four seconds in duration with a two-minute rest between contractions. A pilot test confirmed that the recovery duration between MVCs was sufficient to avoid neuromuscular fatigue. The participants were instructed to give maximal effort and to avoid countermovement. An additional MVC was performed in the event of a countermovement. The participants were given vigorous verbal encouragement during all MVCs

with no feedback (Belkhiria et al., 2017). Each participant was informed of the number of MVCs and asked to avoid pacing (Halperin et al., 2014).

Signal processing

The force and EMG signals were sampled simultaneously at 1 kHz using Biopac MP150 (Biopac System Inc., Santa Barbara, CA), and stored on a personal computer after A/D conversion. The signals were processed off-line using AcqKnowledge 4.3 Software (Biopac Systems Inc., Aero Camino, Goleta, CA, USA). The force signal was smoothed using a digital zero-phase-lag finite impulse response low-pass filter with cut-off frequency of 20 Hz. The full-wave EMG signal was filtered using a digital filter with bandwidths of 10-500 Hz. All subsequent analyses were completed on the filtered signals.

Force and EMG onsets during each MVC were identified using an automated method and checked visually by the same experienced investigator. For each muscle, the onset of EMG activity was determined as the first point of the signal exceeding the 95% confidence interval for baseline activity with minimum duration of 20 ms (Di Fabio, 1987; Inglis et al., 2013). The signal was rectified and numerically integrated for 20 ms. Onset of force signal was defined as the point in the signal where the rate of change rose above 1% of the RFD_{max} (Gabriel et al., 2001; Inglis et al., 2013) (Figure 1).

F_{max} was assessed as the peak of force sustained during each MVC. Additionally, the RMS_{Fmax} was calculated over a 256 ms window centered with the time point of F_{max}. In order to examine the effect of instruction on the phases of explosive force production, the mean force output, elapsed time and RMS amplitude were calculated across five time intervals: between force onset and achieving 25% of F_{max} ($T_{0-25\%}$), between 25 and 50% of F_{max} ($T_{25-50\%}$), between 50 and 75% of F_{max} ($T_{50-75\%}$), between 75 and 90% of F_{max} ($T_{75-90\%}$), and between 90% and F_{max} ($T_{90-100\%}$) (Figure 1).

The RFD_{max} was computed from the differentiated force signal with a moving 20-ms window (Haff et al., 2015; Molina and Denadai, 2012; Penailillo et al., 2013; Sahaly et al., 2001) (Figure1) and was expressed in $N \cdot s^{-1}$. Additionally, the RMS_{RFDmax} amplitude was calculated over a 128 ms window centered with the time point of the RFD_{max}.

The maximum value of the differentiated rectified EMG signal immediately after the EMG onset was calculated for each muscle to assess the rate of muscle activation (Inglis et al., 2013; Mitchell et al., 2011) (Figure 1). The highest value was defined as the maximal rate of muscle activation (RMA_{max}). The electromechanical delay defined as the time difference between the EMG onset and force onset was determined for each muscle (Figure 1). The maximal electromechanical delay (EMD_{max}), i.e., the largest electromechanical delay of the three muscles, was determined for each MVC (Zhou et al., 1995, 1996).

Statistical analysis

Assumptions for normality of distribution for all variables were checked and confirmed using the Shapiro-Wilk test. Dependent variables for each participant were averaged across the main three MVCs before group values were generated for each session. The effect of instruction and session on the dependent variables was analyzed with a two-way repeated measure ANOVA [Instruction (2) × Session (2)]. Likewise, the effect of instruction on the phases of explosive force production was studied using a two-way repeated measure ANOVA [Instruction (2) × Phase (5)]. The location of possible differences was assessed by a Bonferroni post hoc test. The standard error of measurement expressed in relative terms through the coefficient of variation (CV), the intraclass correlation coefficient (ICC), and the corresponding 95% confidence interval (95% CI) was calculated to assess the reliability of the measured variables.

The magnitudes of differences between instructions were expressed as standardized mean differences (Cohen's d effect size) with corresponding 95% CIs (Cohen, 1992). The criteria to interpret the magnitude of the effect sizes were 0–0.19 (trivial), 0.2–0.49 (small), 0.50–0.79 (medium), and > 0.79 (large).

The effect of instruction on the relationship between the RFD_{max}, RMA_{max}, EMD_{max} and RMS_{RFDmax} was studied by multiple linear regression according to the following model:

$$RFD_{max} = a + b \cdot x + c \cdot I + \varepsilon$$

where "x" was the independent variable, i.e., RMA_{max} or EMD_{max} or RMS_{RFDmax}, "I" was a dummy variable corresponding to instruction (I = 0 for the "fast" instruction and I = 1 for the "hard-and-fast" instruction) and ε was the error.

Data are presented as mean and standard deviation (mean ± SD) in the text and tables, but the figures show mean and standard error of the mean (mean ± SE). Statistical procedures were carried out using Statistica Software 10 (StatSoft, Maisons-Alfort, France), and the significance level was set at $p < 0.05$.

Results

Explosive force and neuromuscular parameters

The descriptive statistics of the recorded data and the corresponding CV and ICC for both instructions are presented in Table 1. The analysis revealed no significant interaction effect between the instruction and session for all measured variables (all $p > 0.05$). There was no significant main effect of session for all measured variables, except for the $RMS_{MRFDmax}$ ($F_{1,19} = 5.49$, $p = 0.030$), and no significant main effect of instruction was observed on F_{max} ($F_{1,19} = 0.04$, $p = 0.84$). Moreover, the RMS_{Fmax} tended to be higher with the "hard-and-fast" instruction compared to the "fast" instruction ($F_{1,19} = 4.10$, $p = 0.057$).

A significant main effect of instruction was observed in the RFD_{max} ($F_{1,19} = 50.47$, $p < 0.001$). The post hoc test revealed that the RFD_{max} was significantly higher with the "fast" instruction compared to the "hard-and-fast" instruction (+36.07 ± 10.63%, $p < 0.001$). Likewise, a significant main effect of instruction was observed in the RMS_{RFDmax} ($F_{1,19} = 5.97$, $p = 0.024$). The post hoc test revealed that the RMS_{RFDmax} was significantly higher with the "fast" instruction than with the "hard-and-fast" instruction (+15.10 ± 12.93%, $p = 0.024$).

There was a significant main effect of instruction on the RMA_{max} ($F_{1,19} = 27.88$, $p < 0.001$) and EMD_{max} ($F_{1,19} = 5.44$, $p = 0.031$). The post hoc test revealed that the RMA_{max} was significantly higher with the "fast" instruction compared to the "hard-and-fast" instruction (+37.24 ± 14.76%, $p < 0.001$), whereas EMD_{max} was significantly lower with the "fast" instruction than with the "hard-and-fast" instruction (-3.79 ± 2.49%, $p = 0.030$).

A significant main effect of instruction was observed in $T_{25-50\%}$ ($F_{1,19} = 36.04$, $p < 0.001$). The post hoc test revealed that the time elapsed at the $T_{25-50\%}$ phase was significantly lower with the "fast" instruction compared to the "hard-and-fast" instruction (-50.21 ± 17.50%, $p < 0.001$).

The Cohen's d effect sizes for the

difference between the "fast" and "hard-and-fast" instructions are displayed in Figure 2.

Phases of voluntary force

The average time, force and RMS measured across the phases of force development are displayed in Figure 3. The analysis of the time elapsed in each phase of force development showed a significant main effect of interval ($F_{4,76}$ = 103.68, $p < 0.001$). The post hoc test showed that the time elapsed at the phase $T_{90-100\%}$ was significantly higher than at the preceding phases ($p < 0.001$). Likewise, the time elapsed at the phase $T_{75-90\%}$ was significantly higher than at the preceding phases ($p < 0.05$). No significant effect of instruction ($F_{1,19}$ = 0.03, $p = 0.87$) or interaction between the instruction and interval ($F_{4,76}$ = 1.57, $p = 0.19$) was observed in this variable.

The analysis of mean force production across the phases showed a significant main effect of interval ($F_{4,76}$ = 637.48, $p < 0.001$). The post hoc test showed that mean force increased significantly across the phases ($p < 0.001$). No significant effect of instruction ($F_{1,19}$ = 0.01, $p = 0.92$) or interaction effect between instruction and interval ($F_{4,76}$ = 0.15, $p = 0.96$) was observed in this variable.

The analysis of RMS amplitude across the phases of force development showed a significant main effect of instruction ($F_{1,19}$ = 4.89, $p = 0.03$) and interval ($F_{4,76}$ = 15.77, $p < 0.001$), and an interaction effect between the instruction and interval ($F_{4,76}$ = 12.22, $p < 0.001$). The post hoc test showed that the RMS amplitude was significantly higher at the phases $T_{0-25\%}$ (ES = 0.85 [0.45–1.25], Rating: Large) and $T_{25-50\%}$ (ES = 0.57 [0.23–0.90], Rating: Medium) with the "fast" instruction compared to the "hard-and-fast" instruction ($p < 0.001$).

Relationship between force development and neuromuscular variables

The relationships of the RFD_{max} with the RMA_{max}, EMD_{max} and RMS are displayed in Figure 4. A significant positive correlation was observed between the RFD_{max} and RMA_{max} with a significant effect of instruction:

RFD_{max} = 4499.04 + (0.11·RMA_{max}) - (1364.69·I)
R = 0.80, $p = 0.002$ for RMA_{max} and $p < 0.001$ for I

A significant negative correlation was observed between the RFD_{max} and EMD_{max} with a significant effect of instruction:

RFD_{max} = 8368.68 - (62.16·EMD_{max}) - (1652.22·I)
R = 0.78, $p = 0.012$ for EMD_{max} and $p < 0.001$ for I

A significant positive correlation was observed between the RFD_{max} and RMS with a significant effect of instruction:

RFD_{max} = 4931.81 + (2.95·RMS) - (1640.53·I)
R = 0.77, $p = 0.023$ for RMS and $p < 0.001$ for I

Discussion

The aim of the present investigation was to examine the effect of a verbal instruction on explosive force production and between-session measurement reliability during maximal voluntary contractions of knee extensors. The main finding of this study was that the instruction impacted the RFD_{max} and associated neuromuscular variables (i.e., EMD_{max}, RMA_{max} and RMS). Moreover, the reliability of the measurements was higher with the "fast" instruction compared to the "hard-and-fast" instruction.

Both F_{max} and RFD_{max} measurements are important for explosive movement assessment. In accordance with previous studies (Bemben et al., 1990; Bozic et al., 2012; Holtermann et al., 2007; Sahaly et al., 2001), these measurements were sensitive to the instructions given to the participant by the investigator prior to the contraction task. Bemben et al. (1990) compared F_{max} and the RFD_{max} during isometric handgrip contraction tasks. The authors showed that F_{max} was significantly higher when participants were instructed to reach F_{max} as quickly as possible by squeezing hard and fast (i.e., "hard-and-fat" instruction), whereas the RFD_{max} was significantly higher when participants were instructed to squeeze as fast as possible without any concern into F_{max} (i.e., "fast" instruction). In another study, Sahaly et al. (2001) showed that the RFD_{max} was significantly higher (20 – 46%) when participants were instructed to push as "fast" as possible compared when participants were instructed to push "hard-and-fast" during isometric elbow flexion and leg press exercises. However, the authors reported no significant effect of instruction on F_{max} during these tasks. Likewise, Holtermann et al. (2007) reported a significant difference of the RFD_{max} between the "fast" and the "hard-and-fast" instruction during isometric contractions of the plantar flexors (30.5%, $p < 0.01$). However, no significant difference was observed for F_{max} between the two instructions (0.8%, $p > 0.05$). In the current study, F_{max} was

similar between both instructions. Nevertheless, there was a trend of the RMS at F_{max} to be lower with the "fast" instruction compared to the "hard-and-fast" instruction suggesting possible difference in neuronal strategy within the same contraction.

Table 1

Descriptive statistics of measured variables

		"hard-and-fast" instruction		"fast" instruction		Global effect
		Test	Retest	Test	Retest	
F_{max} (N)	Mean ± SD	697.7 ± 117.2	693.4 ± 120.5	698.4 ± 128.6	688.6 ± 128.7	Instruction: NS
	CV (95% CI)	3.6 (2.7 – 5.2)		2.8 (2.1 – 4.1)		Session: NS
	ICC (95% CI)	0.96 (0.91 – 0.99)		0.98 (0.95 – 0.99)		Interaction: NS
RMS_{Fmax} (μV)	Mean ± SD	352.5 ± 114.8	350.8 ± 123.5	333.2 ± 192.0	319.6 ± 98.8	Instruction: 0.057
	CV (95% CI)	6.4 (4.8 – 9.4)		9.1 (6.8 – 13.5)		Session: NS
	ICC (95% CI)	0.97 (0.94 – 0.99)		0.93 (0.83 – 0.97)		Interaction: NS
RFD_{max} (N·s^{-1})	Mean ± SD	3917 ± 907	4053 ± 855	5880 ± 1066	5597 ± 808	Instruction: **
	CV (95% CI)	16.2 (12.1 – 24.5)		7.3 (5.5 – 10.9)§		Session: NS
	ICC (95% CI)	0.56 (0.16 – 0.80)		0.84 (0.64 – 0.93)§		Interaction: NS
RMS_{RFDmax} (μV)	Mean ± SD	239.4 ± 95.2	230.4 ± 102.9	281.9 ± 105.2	264.5± 114.3	Instruction: *
	CV (95% CI)	9.6 (7.2 – 14.3)		10.4 (7.8 – 15.5)		Session: *
	ICC (95% CI)	0.95 (0.89 – 0.98)		0.93 (0.83 – 0.97)		Interaction: NS
RMA_{max} (μV·s^{-1})	Mean ± SD	7986 ± 3690	7963 ± 4185	11854 ± 3874	11394 ± 3855	Instruction: **
	CV (95% CI)	22.3 (16.6 – 34.2)		9.8 (7.3 – 14.6)§		Session: NS
	ICC (95% CI)	0.85 (0.65 – 0.94)		0.94 (0.85 – 0.98)§		Interaction: NS
EMD_{max} (ms)	Mean ± SD	44.53 ± 5.97	43.37 ± 5.03	42.28 ± 6.56	42.35 ± 6.12	Instruction: *
	CV (95% CI)	7.0 (5.3 – 10.4)		10.3 (7.7 – 15.4)		Session: NS
	ICC (95% CI)	0.74 (0.45 – 0.89)		0.61 (0.24 – 0.83)		Interaction: NS
$T_{25-50\%}$ (ms)	Mean ± SD	60.62 ± 23.29	57.53 ± 16.01	33.97 ± 9.03	36.77 ± 10.94	Instruction: **
	CV (95% CI)	24.6 (18.3 – 37.9)		9.5 (7.1 – 14.1)§		Session: NS
	ICC (95% CI)	0.65 (0.30 – 0.84)		0.90 (0.76 – 0.96)§		Interaction: NS

F_{max}: maximal voluntary force; RMS_{Fmax}: RMS amplitude at F_{max}; RFD_{max}: maximal rate of force development;
RMS_{RFDmax}: RMS amplitude at RFD_{max}; RMA_{max}: maximal rate of muscle activity;
EMD_{max}: maximal electromechanical delay; $T_{25-50\%}$: time elapsed between achieving 25% and 50%
of F_{max}; CV: coefficient of variation; ICC: intraclass correlation coefficient;
95% CI: 95% confidence interval.
§: Above (ICC) or below (CV) the 95% CI observed from the hard-and-fast instruction
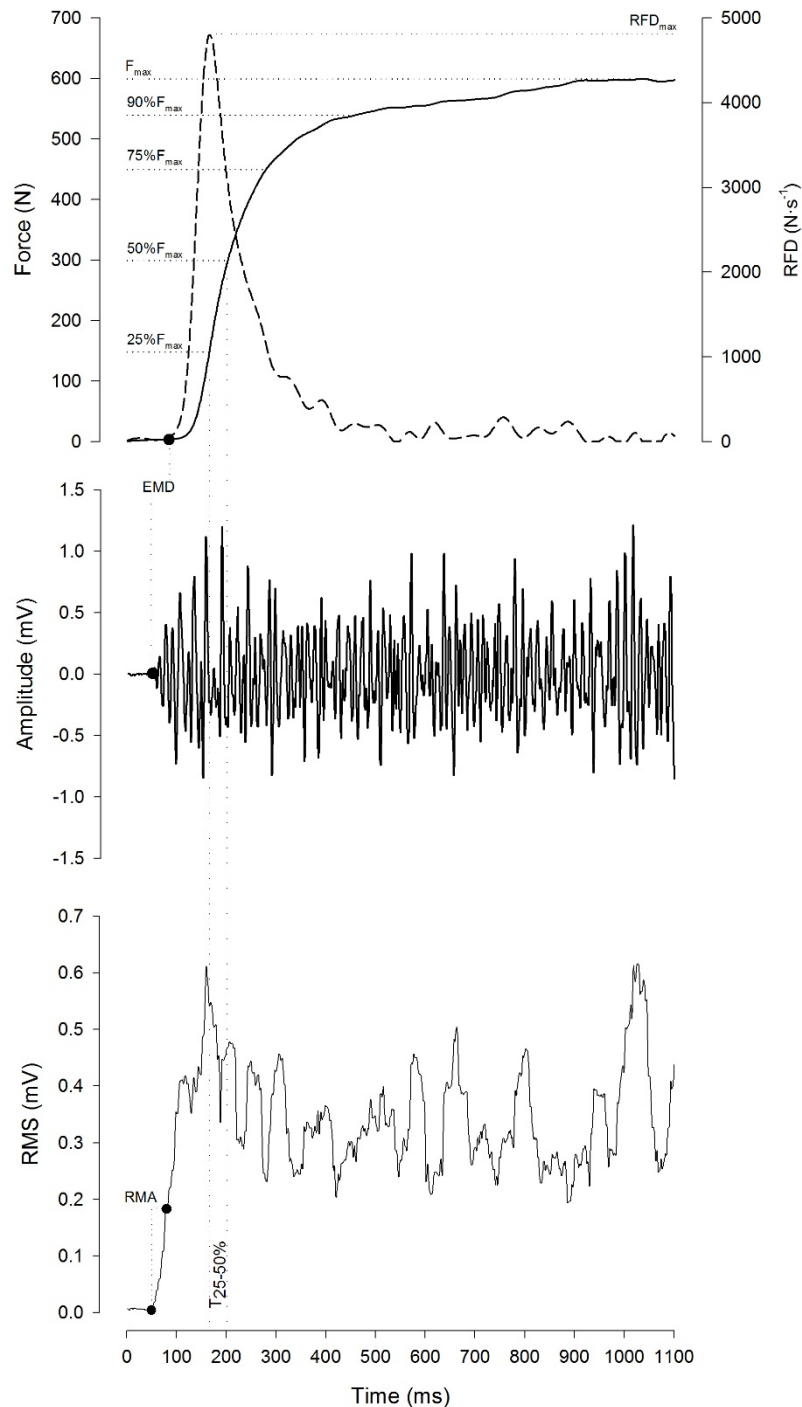**: p < 0.05, **: p < 0.001, NS: non-significant (p > 0.05)*

Figure 1

An example of force–time and EMG–time curves recorded during a maximal voluntary contraction (MVC) with the "fast" instruction. F_{max}: maximal voluntary force; RFD_{max}: maximal rate of force development; EMD: electromechanical delay; RMA: rate of muscle activity. The mean force output, elapsed time and RMS amplitude were calculated across five time intervals: between the force onset and achieving 25% of F_{max} ($T_{0-25\%}$), between 25 and 50% of F_{max} ($T_{25-50\%}$), between 50 and 75% of F_{max} ($T_{50-75\%}$), between 75 and 90% of F_{max} ($T_{75-90\%}$), and between 90% of F_{max} and F_{max} ($T_{90-100\%}$).
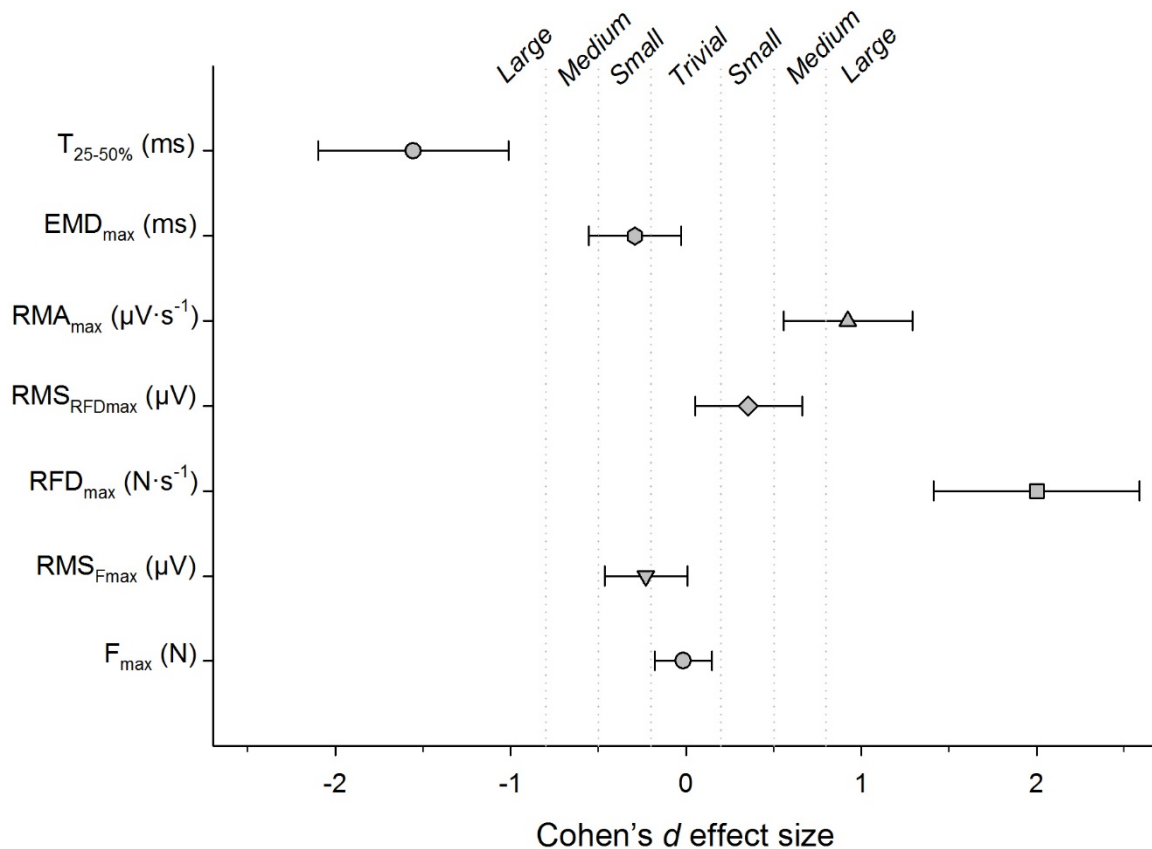
Figure 2

Cohen's d effect size for the difference observed between the "fast" and "hard-and-fast" instructions.
F_{max}: maximal voluntary force; RMS_{Fmax}: RMS amplitude at F_{max};
RFD_{max}: maximal rate of force development; RMS_{RFDmax}: RMS amplitude at RFD_{max};
RMA_{max}: maximal rate of muscle activity; EMD_{max}: maximal electromechanical delay;
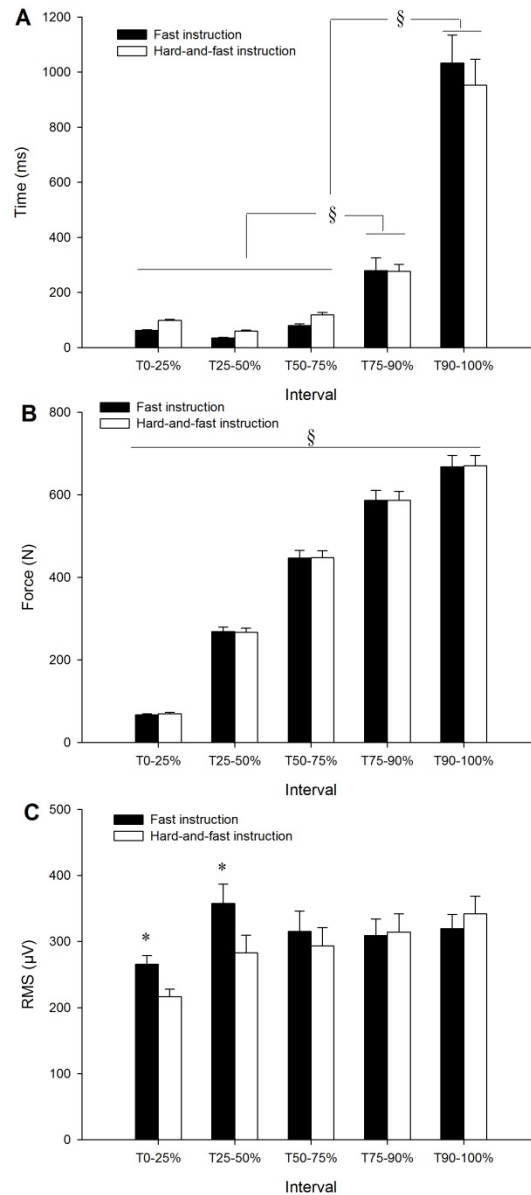*$T_{25-50\%}$: time elapsed between achieving 25 and 50% of F_{max}.*

Figure 3

Mean time (A), force production (B) and RMS amplitude (C) across the phases of force development from the contraction onset (T_0) to F_{max} ($T_{100\%}$). Data show mean ± SE of the two sessions. §: increased significantly among the different phases (p < 0.05). *: Significantly higher with the "fast" instruction compared to the "hard-and-fast" instruction (p < 0.001).
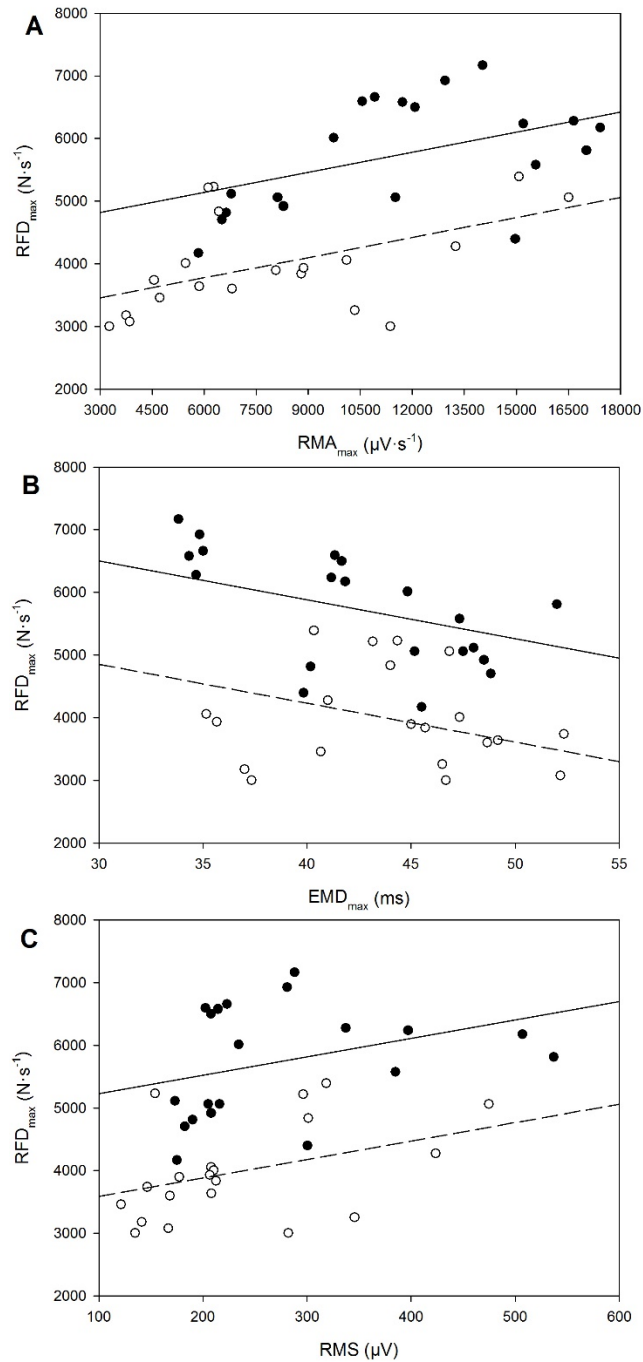
Figure 4

Maximal rate of force development (RFD$_{max}$) plotted against the following variables:
A, maximal rate of muscle activation (RMA$_{max}$); B, maximal electromechanical delay (EMD$_{max}$);
and C, root mean square (RMS). A solid line and black symbols
correspond to the "fast" instruction, whereas a dashed line
and empty symbols correspond to the hard-and-fat instruction. Data are the mean of both sessions.

In accordance with the previous studies (Holtermann et al., 2007; Sahaly et al., 2001), the RFD_{max} in the current study was higher with the "fast" instruction compared to the "hard-and-fast" instruction ($36.07 \pm 10.63\%$) with large effect size (2.0 ± 0.59). Interestingly, the higher RFD_{max} values observed with the "fast" instruction were associated with greater muscle activation of the agonist muscles during the phase of force development (i.e., from the contraction onset to achieving 50% of F_{max}). These findings were most likely due to a central factor since the RFD_{max} was primarily a factor of agonist neural drive. During the activation of knee extensors, their motor neurons are facilitated by motor commands from supraspinal centers via the corticospinal tract. Because the participants were asked to voluntarily extend the knee as fast as possible against the force transducer, this would invoke a motor command from the supraspinal centers (Johnson et al., 2015). The higher values of the RFD_{max} with the "fast" instruction were concomitant with higher values of the RMA_{max} and RMS amplitude. The relations within the RFD_{max}-RMA_{max} and RFD_{max}-RMS were significantly positive.

The rate of rise of the muscle's activity (i.e., RMA) at its onset may be affected by earlier motor unit recruitment, a higher discharge rate and a higher rate of doublet discharge, defined as two proximate spikes, less than 5 ms apart (Van Cutsem et al., 1998). Therefore, a higher RMA_{max} involves higher motor unit discharge rates. Indeed, the RMA is controlled by the muscle fiber action's potential conduction velocity, which has been shown to relate linearly to the EMG power spectrum (Lindstrom et al., 1970; Stulen and DeLuca, 1981). Moreover, the activation of the fibers influences the rate of cross bridge cycling. If the individual sarcomeres within a muscle fiber can be activated more quickly, the shortening velocity of the whole fiber would be enhanced (Wickiewicz et al., 1984). Indeed, in the current study, the time elapsed in the phase $T_{25-50\%}$, in which the RFD_{max} occurs, was significantly lower with the "fast" instruction compared to the "hard-and-fast" one.

The relation within the RFD_{max}-EMD_{max} was significantly negative. During skeletal muscle contractions, EMD reflects both electrochemical and mechanical processes (Cavanagh and Komi, 1979; Zhou et al., 1995). Electrochemical processes include synaptic transmission, action potential propagation across the sarcolemma, excitation-contraction coupling process, Ca^{2+} release into the sarcoplasm, with subsequent Ca^{2+} binding to active sites and the formation of cross-bridges. Mechanical processes include force transmission along the active and passive parts of the series elastic component and stretching of the series elastic component by the contractile elements (Cavanagh and Komi, 1979; Zhou et al., 1995). Therefore, any factor influencing these processes may influence EMD. However, the time course of the stretching of the series elastic component by the contractile component is considered a major portion of EMD time (Cavanagh and Komi, 1979). The changes in electrochemical rather than mechanical processes could be explained by the lower EMD values with the "fast" instruction.

Reliability refers to the consistency of a measurement which can be assessed by various methods (Weir, 2005). Generally the first step when testing the reliability is to examine statistically the difference between the two measures (Weir, 2005). In the present study, there were no statistical differences between test and retest sessions for any of the measured variables. However, statistical bias does not give a sensitive indication of random variation between measures. Therefore, Weir (2005) recommends quantifying reliability by means of the ICC and CV. The ICC is considered as high for values above 0.90, moderate for values between 0.80 and 0.90, and low for values below 0.80 (Vincent, 2004). The reliability of F_{max} in the present study was high for both instructions. These findings were in agreement with previous studies on the reliability of F_{max} during various MVC tasks (Bemben et al., 1990; Blazevich et al., 2002; Maffiuletti et al., 2007; Mirkov et al., 2004).

Furthermore, the reliability of F_{max} was somewhat higher than of the RFD_{max}. These observations may be due to some methodological issues regarding the determination of the RFD_{max}. Indeed, various sampling windows have been proposed for the assessment of the RFD_{max}. The differentiated force signal with a moving 20-ms window was the most used method to assess the RFD_{max} (Haff et al., 2015; Molina and Denadai, 2012; Penailillo et al., 2013; Sahaly et al., 2001). In a reliability study, Haff et al. (2015) reported high reliability of a 20 ms sampling window (ICC =

0.90, 90% CI = [0.73–0.97]; CV = 12.9%, 90% CI = [0.5–20.7]) compared to 2, 5, 10, 30 and 50 ms sampling windows during isometric mid-thigh clean pull tasks. In the current study, high variability of the RFD_{max} was observed with the "hard-and-fast" instruction compared to the "fast" instruction, suggesting the latter one is better for the RFD_{max} assessment. Based upon the data collected in the current study it is clear that strength and conditioning professionals need to carefully consider the instruction used to assess the RFD_{max} during the MVCs as the present study demonstrates that the instruction impacts the reliability of the measurement. This becomes an increasingly important consideration when the purpose of the assessment is to monitor performance and track changes in neuromuscular performance over time particularly in individuals involved in sports activities in which explosive force production is fundamental.

Conclusion

The instruction given by the investigator prior to a MVC task impacts the reliability of neuromuscular performance. The instruction should emphasize the importance of contracting skeletal muscles as fast as possible to maximize the RFD_{max}. Moreover, attempting to achieve high values of F_{max} and the RFD_{max} within the same MVC may result in low reliability of the measures. These findings have several practical implications for practitioners and researchers who are involved with both explosive movements and potentially injurious situations.

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