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Evaluation of Consecutive Maximum Contractions as a Test of Neuromuscular Function

by
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The aim of the study was to conduct a preliminary evaluation of consecutive maximum contractions (CMC) as a test of neuromuscular function. Eleven participants performed externally paced isometric CMC (i.e., a series of consecutive maximum force exertions and relaxations) of the quadriceps muscle. The derived variables included the peak forces, and the maximum rates of force development and relaxation. The results revealed high within-day reliability of CMC variables, while their correlations with the jumping performance were consistently higher than those of the variables of the standard strength test (SST). CMC variables also showed fairly stable values across a wide range of frequencies, while their peak force revealed a strong relationship with maximum force of SST despite being about considerably lower. Therefore, we conclude that CMC could be developed into a standard test of neuromuscular function. In addition to capturing the muscle actions based on different neural activation pattern than SST, CMC could also be based on simpler testing procedure, lower force exertion, and self-selected frequencies.
Keywords: quadriceps, muscle, force, isometric, strength, reliability, validity

Introduction

Taking into account the vast importance of voluntary movements in human life, the extensive assessment of neuromuscular function in human movement disciplines (e.g., physical therapy, rehabilitation, neurology, ergonomy, sports and physical education) should not be considered surprising (Abernethy et al. 1995; Wilson and Murphy 1996; Rainoldi et al. 2001; Aasa et al. 2003; Weir 2005). Neuromuscular assessments have been used to assess various functional and intervention aspects, such as the deficiencies of the neuromuscular system, imbalance in functional abilities of antagonistic muscular groups, ability to perform various functional tasks, effects of various pharmacological interventions and rehabilitation procedures, or changes in muscular function associated with various diseases or aging (Abernethy et al. 1995; Wilson and Murphy 1996; Ugarkovic et al. 2002; Jaric 2002; Jaric et al. 2005).

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In ergonomic, and sport and exercise related activities the neuromuscular function has been usually assessed through muscle strength that measured the maximal amount of force a muscle or muscle group can generate in a specified movement pattern at specified velocity of movement (Knuttgen and Kraemer 1987). In particular, the standard strength tests (SST; ((Abernethy et al. 1995)) involve either the maximum isometric or concentric contraction exerted either against a single force transducer or standard 'isokinetic devices' (Wilson and Murphy 1996; Jaric 2002), or against a submaximal external load (often known as 'one repetition maximum' tests; (Abernethy et al. 1995)). By far, the most often recorded dependent variable of SST is the maximum force or load lifted (Fmax) (Abernethy et al. 1995; Sahaly et al. 2001; Jaric 2002; Jaric et al. 2005) typically achieved after 3-5 s of a sustained contraction. The face validity of Fmax has been based on its presumed correspondence with the maximum force that the particular muscle can exert in various force demanding functional tasks.

Although widely used, the SST are known to have several shortcomings. Probably the most important one originates from the differences in neural activation pattern between the rapid and sustained maximum contractions. Namely, numerous functional movements are based either on relatively brief actions of particular muscle groups (e.g. rapid discrete movements such as reaching and repositioning objects, or postural corrections), or on consecutive actions of antagonistic muscle groups (walking, running, throwing, kicking). For example, both the duration of rapid pointing movements and the time allotted to prevent a fall may be within 200 ms, or less (Kukolj et al. 1999; van den Bogert et al. 2002; Domkin et al. 2005). The muscle activation in such movements is characterized by high instantaneous discharge rates that decline during successive firing (Desmedt and Godaux 1977; Van Cutsem et al. 1998) and, therefore, the force exertion depends greatly on neural activation of the muscle fibers at the start of contraction (de Ruiter et al. 2004; de Ruiter et al. 2006). For contractions that produce a gradual increase in muscle force until the maximum is reached (such as in SST), there is a progressive increase in discharge rate (Enoka and Fuglevand 2001). Moreover, for rapid force exertions a higher rate of motor neuron firing is necessary than for the production of maximum force (Hakkinen et al. 1985; Van Cutsem et al. 1998; Aagaard et al. 2002) and the higher initial firing rate is partly achieved through doublet discharges which could contribute to higher force maximums achieved in the subsequent contraction phases (Burke et al. 1976; Miller et al. 1981). Therefore, it has been also concluded that the consecutive phases of a single rapid force development could depend on different neural and physiological mechanisms (Andersen and Aagaard 2006). As a result, the assessment of the abilities to exert a sustained maximum force (as assessed by SST) and to exert it rapidly (typical for a number of functional movements based on brief muscular actions) could require separate methods of evaluation ((Bemben et al. 1990; Sahaly et al. 2001); also see further text).

In addition to the above discussed differences in the muscle activation pattern (see previous paragraph), SST are known to have other shortcomings. For example, SST based on direct force recording have infrequently been applied also to record the maximum rate of force development (RFDmax) which corresponds to the maximum of the time derivative of exerted force (Wilson and Murphy 1996; Mirkov et al. 2004; Andersen and Aagaard 2006). However, based on the above considerations, it should not be considered as surprising that the instructions "to exert maximum force" and "to exert it rapidly" have partly different effects on the outcome of SST assessed through Fmax and RFDmax (Bemben et al. 1990; Sahaly et al. 2001). As a consequence, separate series of trials are needed to evaluate Fmax and RFDmax which could also lead to a prolonged testing procedure associated with muscle fatigue (Abernethy et al. 1995; Wilson and Murphy 1996). Moreover, one could also argue that the relationship between Fmax and RFDmax still remains unknown. Although several studies have demonstrated a positive relationship between them (Mirkov et al. 2004), particularly for the RFDmax recorded in a later phase (Aagaard et al. 2002), the available data remain mainly inconsistent (Wilson and Murphy 1996; Holtermann et al. 2007). One of the reasons why RFDmax assessment has been infrequently applied is that it requires longer familiarization than Fmax (Wilson and Murphy 1996; Sahaly et al. 2001). Furthermore, although the rate of force relaxation (RFR) could be equally important as RFD for success of rapid consecutive actions of antagonistic muscles, it has been almost completely neglected in SST procedures (Andersen and Aagaard 2006). Finally, the exertion of a sustained contraction that provides Fmax could be painful or inappropriate for some individuals such as the frail elderly or injured/recovering persons (Wilson and Murphy 1996).

Taking into account the above listed shortcomings, it should not be surprising that SST have demonstrated a relatively low external validity when used to assess functional performance. This finding has been consistently observed in the literature (Abernethy et al. 1995; Driss et al. 1998; Kukolj et al. 1999; Paasuke et al. 2001; Jaric 2002; Jaric et al. 2002; Ugarkovic et al. 2002; Andersen and Aagaard 2006), with relatively few exceptions suggesting only moderate relationships (Jaric et al. 1989; Paasuke et al. 2001; Wisloff et al. 2004). Therefore, there is an apparent need for development of either new or complementary tests for the evaluation of neuromuscular function. Those tests should address at least some of the above listed shortcomings, such as by being based on brief and rapid force exertions, requiring exertion of moderate forces (relative to Fmax) within a fewer number of trials, and allowing for the assessment of RFR.

The main aim of the present study is to conduct a preliminary evaluation of the consecutive maximum contractions (CMC; brief contractions followed by relaxation externally paced by a metronome) as a test of neuromuscular function. The main rationale for this selection is the general correspondence of CMC with the regime of muscular contraction typical for rapid and cyclic movement, rather than with long lasting force exertions that are also typical for SST. In particular, we evaluated the within-day reliability of CMC variables and assessed their external validity with respect to the counter movement jump (CMJ) performance. We also assessed the effect of frequency on the CMC variables and related them with the variables obtained from SST. The results are expected to lead to a further development of CMC into a novel and, perhaps, a complementary (with respect to SST) test that could be routinely used for the assessment of neuromuscular function.

Methods

Subjects

Male students of the Faculty of Sport and Physical Education (N = 11) participated in the study. Their mean (SD) age was 22 (3) years. The participants could be considered as physically active ones since although none of them was an active athlete, they all participated in courses of physical activities on a daily basis through their standard academic curriculum. The participants' mean (SD) body mass and height were 79.7 (5.9) kg, and 1.85 (4) m, respectively, while the body mass index was 23.3 (1.5) with the range 20.4-25.2. None of them reported health problems or recent injuries. They were familiar with both the standard strength tests (SST) and the maximum countermovement jump (CMJ; see further text for details) due to regular semi-annual testing of physical abilities, as well as due to their participation in various athletic activities through their academic curriculum. The measurement procedures and potential risks were verbally explained to each participant prior to obtaining an institutionally approved informed consent according to the Helsinki Declaration.

Testing procedure

The testing procedure consisted of the familiarization and experimental session performed with 1-2 days of rest. Each session was preceded by a standard 10-min warming up and stretching procedure. Within the familiarization session subjects performed total of 21 trials of consecutive maximum contractions (CMC; 3 trials per each of the 7 frequencies; see further text for details) in random sequence. Within the experimental session subjects performed 3 consecutive trials at each frequency in random sequence. The first trial was considered as practice, while the data from the remaining two were recorded for further analysis. The SST and the maximum vertical jumps (CMJ; see further text) were conducted only within the experimental session. To avoid the effect of fatigue, SST was conducted at the end of the experimental session.

Experimental testing

Subjects sat on a bench in a sitting position with their thighs and trunk tightly fixed with belts. The shank of the dominant leg was connected to a calibrated strain-gauge force transducer (Hottinger, Type S9, range 10 KN; linearity better than 1%, tensile/compressive force sensitivity 2mV/N) by a wrist band positioned just above the lateral malleolus. The knee angle was fixed at 100º.

Consecutive maximum contractions (CMC). The test selection was based on its presumed similarity with various rapid and cyclical movements regarding both the kinetic and neural activation pattern of the muscle force exertion (see Introduction for details). The subjects were instructed to "achieve the maximum quadriceps force against the band as soon as possible and, thereafter, to relax, as when performing consecutive kicks" paced by a metronome set to 0.67, 1.00, 1.33, 1.67, 2.00, 2.33 and 2.67 Hz. The feedback regarding the current force was showed at a computer monitor and a verbal encouragement was also provided. The trial duration covered 8 full periods of CMC force. The experimental trials were repeated when the contractions showed inconsistent force profiles and/or force timing, as well as when the exerted force did not sufficiently relax to drop within the interval of ±5% of peak force. That often happened only at the highest frequencies (i.e., 2.67, 2.33 and, occasionally, 2.00 Hz). The rest intervals between two consecutive trials were 2 min.

Standard strength test (SST). We selected the maximum isometric exertion of muscle force as the most frequently applied strength test ((Abernethy et al. 1995; Jaric 2002; Jaric et al. 2005); see also Introduction). The isometric quadriceps strength was tested using the same set-up as applied in the CMC test. The subjects were instructed to "achieve the maximal force against the band as soon as possible and to retain it"(Wilson and Murphy 1996). The duration of the force exertion was 4 s. The same computer monitor was used to provide feedback information and verbal encouragement was also used. One practice and two testing trials were performed. The testing trial with higher maximum force was taken for further analysis. The rest intervals between two consecutive trials were 2 min.

Countermovement jump (CMJ). This task was selected because it represents the most frequently applied test of both the rapid movement performance and muscle power (Abernethy et al. 1995; Markovic and Jaric 2007). The height of the maximum CMJ performed without an arm swing was calculated from the flight time measured by an ErgojumpTM apparatus (Bosco system) (Bosco et al. 1983). The jump was repeated three times, and the best result was taken for further analysis.

Several weeks following the experimental data collection, we performed a brief pilot test on another 12 male students who were naïve regarding the aim of the study. We simply instructed them to perform two consecutive CMC trials not only without any familiarization, but also without pacing them with the metronome. The results of the second trial averaged across the participants revealed the 'self-selected' CMC frequency of 1.5 (0.4) Hz. The range was 0.9-2.1 Hz.

Data processing and analysis

A custom made LabView program was used for data acquisition and processing. The force-time curve of the quadriceps muscle was recorded at a rate of 500 s-1 and low-pass filtered (10 Hz) using a fourth-order (zero-phase lag) Butterworth filter. The force maxima provided the peak force (PF) of CMC, and the maximum force (Fmax) of SST. Thereafter, a derivative of the force-time curves was calculated within a 20 ms moving window. The maxima and minima revealed the rates of force development (RFD) and relaxation (RFR) of CMC, respectively, as well as the maximum rate of force development of the SST (RFDmax; see Figure 1 for illustration). CMC variables were calculated as average values obtained from the last three periods of the recorded force and averaged across two trials. The same LabView program also provided on-line force profiles for visual inspection, as well as a warning if CMC frequency differed from the prescribed one, or if the tested muscle did not sufficiently relax (see previous text for details).

Descriptive statistics were calculated for all experimental data. To assess the within-day reliability of each dependent variable obtained from SST (i.e., Fmax and RFDmax) and CMC (PF, RFD, and RFR), the correlation coefficients between the first and second trial were calculated. In addition, a paired t-test was applied to detect a systematic bias between two trials (Weir 2005). The external validity of the evaluated tests was assessed by correlation coefficients calculated between each variable and height of CMJ. One-way repeated measures ANOVA was used to explore the effect of frequency on each of the CMC variables. Thereafter, the correlation coefficients were also calculated both among the CMC variables and between the corresponding CMC and SST variables. The level of statistical significance was set to p = 0.05.

Results

Figures 1A & B show typical force-time curves of the SST that allowed for the assessment of Fmax and RFD max of the tested muscle. Figures 1C & D show force profiles obtained from consecutive maximum contractions performed under the minimum, middle and maximum frequency. Excluding the highest frequencies, a visual inspection suggests that the most of the data revealed consistent profiles with minimum forces strikingly close to zero. The results also suggested a relatively weak effect of frequency on PF and virtually no effect on the rates of force change (i.e., RFD and RFR). Note also that the shape of the force profile exerted under the lowest frequency suggested a ceiling effect despite the fact that PF was on average 15% lower than Fmax recorded in SST. This finding was fairly consistent across the subjects.

Table 1 shows the main results of the study. In general, the within-day reliability of the variables obtained from both SST and CMC performed under different frequencies proved to be high since the correlations observed between two consecutive trials were between 0.96 and 1.00. Only a few variables suggested a significant (albeit moderate) difference between the means.

Height of CMJ (the maximum values of three consecutive trials) was 38.2 (4.4) cm. All three CMC variables obtained under seven different frequencies demonstrated a significant positive

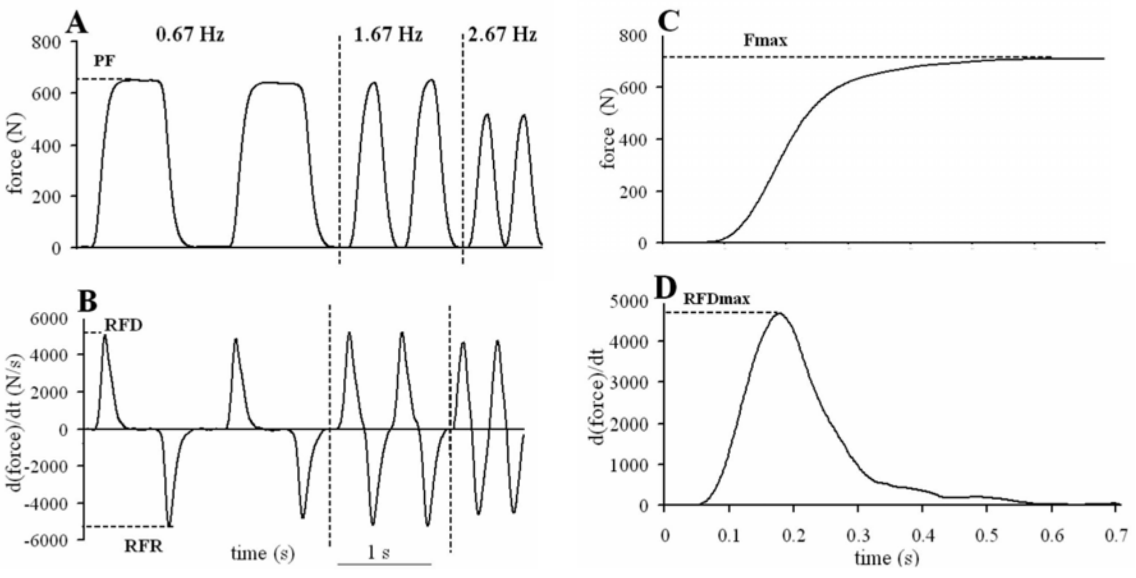

Figure 1

(A) Force time series recorded in a representative subject under the lowest, medium and maximum frequency of the consecutive maximum contractions (CMC). The maxima of the force profiles represent the peak force (PF). (B) The corresponding time derivatives served for recording maximum rate of force development (RFD) and relaxation (RDR). (C) Force profile of the standard strength test (SST) performed on the same subject. Maximum force (Fmax) and the rate of force development (RFDmax; panel D) were taken for further analysis.

Table 1

Results obtained from the standard strength test (SST) and consecutive maximum contractions (CMC).

	SST		CMC								
			0.67 Hz			1.00 Hz			1.33 Hz		
	Fmax (N)	RFDmax (N/s)	PF (N)	RFD (N/s)	RFR (N/s)	PF (N)	RFD (N/s)	RFR (N/s)	PF (N)	RFD (N/s)	RFR (N/s)
T1	703 (135)	4477 (711)	673 (129)	4490 (753)	-5082 (1209)	663 (128)	4524 (679)	-5094 (1190)	673 (119)	4698 (643)	-5380 (1392)
T2	705 (134)	4609 (625)	660 (123)	4358 (714)	-4766 (1368)	654 (114)	4479 (746)	-4956 (1096)	664 (111)	4627 (653)	-5275 (1265)
r (T1-T2)	1	0.97	1.00§	0.96	0.98§	1	0.97	0.99	1	0.99	0.98
r (CMJ)	0.57	0.53	0.7*	0.84*	0.77*	0.67*	0.66*	0.81*	0.67*	0.76*	0.8*

CMC											
1.67 Hz			2.00 Hz			2.33 Hz			2.67 Hz		
PF (N)	RFD (N/s)	RFR (N/s)	PF (N)	RFD (N/s)	RFR (N/s)	PF (N)	RFD (N/s)	RFR (N/s)	PF (N)	RFD (N/s)	RFR (N/s)
649 (117)	4858 (781)	-5333 (1397)	624 (111)	4848 (751)	-5504 (1238)	588 (105)	4795 (755)	-5462 (1074)	553 (88)	4698 (643)	-5359 (872)
637 (109)	4675 (707)	-5255 (1402)	620 (108)	4657 (659)	-5328 (1218)	587 (103)	4761 (703)	-5464 (1162)	553 (88)	4686 (572)	-5306 (922)
1	0.97	0.99	1	0.97	1.00§	1	0.98	0.98	0.99	0.98	1
0.75*	0.66*	0.76*	0.7*	0.7*	0.73*	0.73*	0.61*	0.74*	0.62*	0.68*	0.7*

correlation with CMJ (Table 1). The same correlation calculated for Fmax and RFDmax were somewhat below the significant level. When compared, the correlation coefficients of PF with CMJ were significantly higher than 0.57 observed between Fmax and CMJ, while the same correlations of RFD and RFR were higher than 0.53 observed from RFD max ($p<0.05$; one group t-tests). Finally, note that PF observed under lower four frequencies (i.e., those that demonstrated the highest values of PF; see further text for details) revealed values about 17% lower than Fmax.

Of particular importance for potential routine application of CMC could be the effect of frequency on the derived variables (Figure 2). In general, the results suggested only a relatively weak effect of frequency on PF ($F[1,6]=38$, $p<0.05$; Figure 2A), RFD ($F[1,6]=2.96$, $p<0.05$; Figure 2B) and RFR ($F[1,6]=2.56$ $p<0.05$; Figure 2C). The post-hoc tests revealed no significant differences in PF within the range of 0.67-1.67 Hz. Moreover, RFR only revealed significantly higher value in 2.33 HZ than in 0.67, while the post-hoc test of RFD revealed no significant effects of frequency.

Finally, we wanted to assess the relationship among the variables obtained either from the same test or between different tests. Regarding SST, the correlation coefficient between Fmax and RFD max was $r=0.80$ ($p<0.05$). Having in mind both the stable values of PF under the lower and medium frequencies (see previous paragraph) and the familiarization problems that the participants had with performing CMC at the highest frequencies, only the CMC variables obtained under the frequencies of 1.33 and 1.66 Hz assessment were taken into ac-

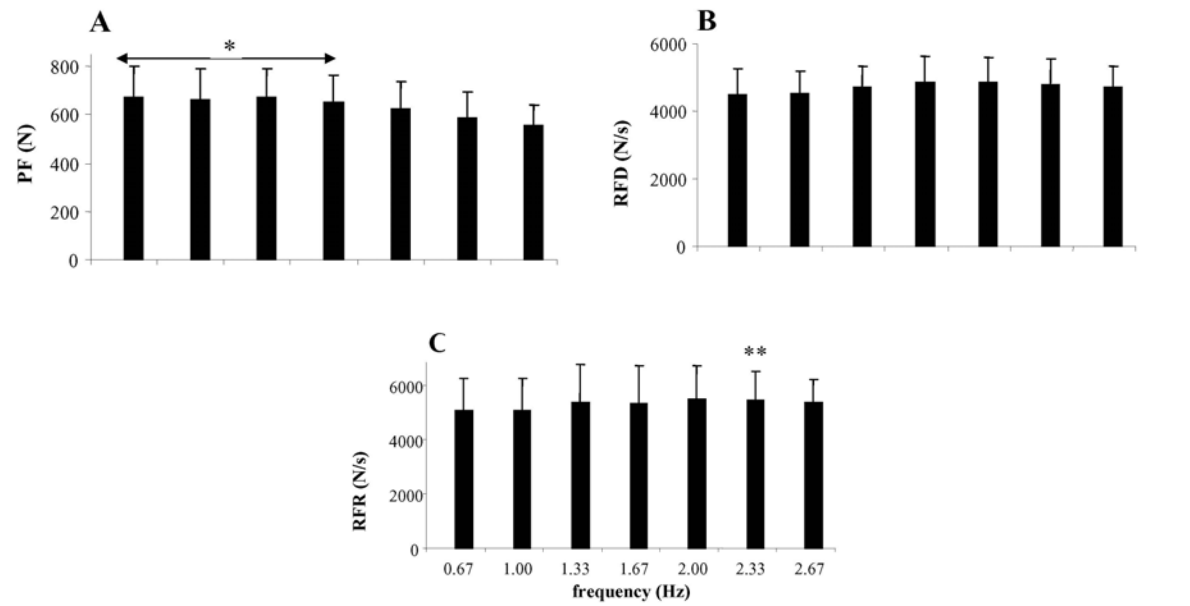

Figure 2

Dependent variables obtained from CMC: peak force (PF; A), and the rates of force development (RFD; B) and relaxation (RFR; C). The data are averaged across the subjects (error bars represent SD). * - significantly lower than the first four frequencies; ** - significantly different from 0.67 Hz

count. Note also that these frequencies were closest to the 'self-selected' ones (see Methods for details). The results revealed moderate correlations between PF and RFD, and RFD and RFR (Table 2). However, the correlation coefficients between PF and RFR were remarkably high. Finally, regarding the relationship between the corresponding variables of CMC and SST, the correlations of both RFD and RFR with RFDmax were moderate. However, although PF was considerably lower than Fmax (see previous paragraphs), the correlation coefficient between them was exceptionally high.

Discussion

The aim of the study was to carry out a preliminary evaluation of the consecutive maximum contractions (CMC) as a candidate for a standard test of neuromuscular function. The most important findings are those related to the reliability and external validity of the derived variables, their change associated with the change in CMC frequency, as well as the relationships both among themselves and with the variables obtained from the standard strength test (SST).

The evaluation of both the reliability and validity of the CMC showed encouraging results. All three variables revealed exceptionally high within-day reliability, while their relationship with the countermovement jump height (CMJ) was consistently stronger across all frequencies than the same relationship revealed by Fmax and RFDmax. The later finding suggests that CMC better captures neural activation pattern of brief maximum muscular action associ-

Table 2

Correlations among the variables obtained from consecutive maximum contractions (CMC; only those performed at 1.33 and 1.67 Hz) and standard strength test (SST)

	PF – Fmax	RFD - RFDmax	RFR - RFDmax	PF - RFD	PF - RFR	RFD - RFR
1.33 Hz	0.95	0.69	-0.70	0.80	-0.92	-0.74
1.67 Hz	0.89	0.64	-0.63	0.67	-0.93	-0.64

PF – peak force (CMC), RFD - rate of force development (CMC); RFR – rate of force relaxation (CMC); Fmax - maximum force(SST); RFDmax –rate of force development (SST); all correlations are significant at $p<0.05$ level.

ated with CMJ than SST. The ceiling effect observed in CMC showing a low force plateau relative to Fmax also speaks in favour of the assumption that CMC and SST are based on different control patterns. This assumption is in line with the experimental evidence that the pattern of neural activation for rapid force exertion and for gradual exertion of maximum force exertion could be considerably different ((Enoka and Fuglevand 2001; Andersen and Aagaard 2006; de Ruiter et al. 2006), see also Introduction for details). Excluding the highest frequencies, CMC was also easy to familiarise with. PF of CMC was both considerably lower and of the shorter duration than Fmax which could be of particular advantage when testing neuromuscular function in frail elderly or injured/recovering individuals. Based both on these and other considerations (for details see further text), one could conclude that CMC deserve attention as a candidate for routine assessment of neuromuscular function.

A potentially confounding effect in future application of this type of muscle action is the effect of the frequency of CMC on the dependent variables. Thus, we intentionally tested CMC within the full physiological range and the results suggested that the highest frequencies (i.e., 2 Hz and higher) should be discarded in future studies. The reasons for that could be the relatively long periods needed for familiarization, decreased PF and, occasionally, a lack of full muscle relaxation at higher frequencies. If future findings appear to be in line with the findings of our brief pilot testing carried out on naive subjects without external pacing, CMC could be performed under a 'self-selected frequency' which could additionally simplify the testing procedure.

Regarding the correlations among the CMC variables, the results suggest a moderate relationship between PF and RFD, which is in line with the moderate relationship between Fmax and RFDmax obtained from SST (Jaric et al. 1989; Wilson and Murphy 1996; Mirkov et al. 2004). This finding should not be considered surprising since the abilities to exert a high maximum force and to exert it rapidly could partly depend on some common factors, such as muscle size, and cross-sectional area and muscle fibre type (Harridge et al. 1996; Wilson and Murphy 1996; Mirkov et al. 2004). However, if future studies support the obtained strong relationship between PF and RFR, the ability for quick muscle relaxation (as assessed by RFR) could be omitted from future CMC testing.

Of higher importance then the correlations among CMC variables could be the relationship between the same variables and those observed from SST. Both a moderate relationship between RFD and RFDmax and a low level of PF relative to Fmax strongly suggest that CMC and SST capture different neural activation mechanisms of the same muscle. As a result, one could conclude that these two tests are complementary ones since CMC is likely to depict the muscle ability to quickly exert force over a short time period, while SST evaluates the muscle ability to exert a high maximum muscle force over a prolonged period of time. However, PF also demonstrated an exceptionally strong relationship with Fmax. If future results support this finding, CMC may not be a complementary test to SST, but an independent test of neuromuscular function that provides two variables depicting muscle abilities relevant for two distinct groups of movement tasks. Specifically, while RFD could describe the ability for rapid force production, PF could describe the muscle ability for exerting sustained maximum forces even without exposing both the muscle and the connective tissues to them.

Despite some encouraging preliminary findings, a number of additional aspects remain to be explored prior to proposing CMC as a standard test of neuromuscular function. First, a proper evaluation of CMC reliability needs to be established on a timescale that is relevant for monitoring various interventions (e.g., days/weeks; (Weir 2005)) Similarly, the sensitivity of CMC for detecting changes in neuromuscular function associated with various long-term (e.g., training or rehabilitation) or short-term (e.g., pharmacological, warming-up) interventions needs to be established on similar time scales. Second, the external validity of CMC needs to be evaluated on both different populations and a wider range of functional movement tasks that are associated with different types of muscular action (Rainoldi et al. 2001; Markovic and Jaric 2007). The results could provide additional findings relevant for the already discussed problem whether CMC could be an independent test of neuromuscular function, or a test complementary to SST. Third, note that the present study did not provide unambiguous findings regarding the relationships among CMC variables, as well as between the CMC and the SST variables. Fourth, note that SST applied in routine batteries of tests of physical abilities are performed on very few muscle groups presuming that the findings could be generalized across the entire muscular system. Similarly, CMC need to be performed on various muscle groups to explore the generalizability of the obtained variables. Finally, from the methodological aspect, it would be of importance to assess whether CMC could be tested over a shorter time intervals than those applied in the present study which could additionally simplify the experimental procedure.

Regardless of the above discussed unresolved issues, we could conclude that the present findings encourage further developing of CMC into a standard test of neuromuscular function. In particular, the present data suggest that it could be both reliable and valid. Of particular importance could also be that CMC could not only quantify the ability for production of sustained maximum forces (suggested by high correlation of PF with Fmax), but also the ability for force production as it relates specifically to a number of important daily tasks, such as both brief discrete and cyclical muscular actions, postural corrections, or injury preventing movements. Note also that the exerted forces could be considerably lower than those exerted in SST. Regarding the methods of future application, CMC could be based on very few experimental trials performed at self-selected frequency, while the only dependent variables extracted could be PF and RFD. Finally, note that although CMC recording could be conducted using a single force transducer (such as in the present study), the same test could also be performed on a standard' isokinetic apparatus'.

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