Reproducibility of velocity-dependent power: before and after lengthening contractions

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Abstract: The determination of power using isokinetic testing has been shown to be highly reliable. However, isotonic and isokinetic testing involve specific mechanical constraints that likely necessitate different neuromuscular strategies. Therefore, the purpose here was to establish test–retest intrarater reliability (separated by 7 days) of loaded maximal shortening velocity and velocity-dependent power of the ankle dorsiflexors using the isotonic mode of the Biodex dynamometer (*i*) at baseline and (*ii*) throughout recovery following 150 high-intensity lengthening contractions. Intraclass correlation coefficients $(ICC)_{2,1}$ with 95% CIs were used to determine relative reliability, whereas absolute reliability included typical error (TEM) and typical error expressed as a coefficient of variation (TEM_{CV}). Twenty-four young men and women volunteered for the study. Maximal shortening velocity and power were determined with a fixed resistance set at 20% of maximal voluntary isometric contraction across 2 testing sessions separated by 7 days. ICCs were 0.93 and 0.98 for maximal shortening velocity and peak power, respectively. Following the lengthening contractions, ICCs indicated high reliability for maximal shortening velocity and peak power, 0.86 and 0.94, respectively, suggesting that a similar amount of fatigue was incurred on both days. Measures of absolute reliability for maximal shortening velocity and peak power also yielded high reliability. The isotonic mode is highly reliable when testing velocity-dependent power of the ankle dorsiflexors at baseline and following fatiguing lengthening contractions. The high reliability of this measure is encouraging and suggests that the isotonic mode can be used in various settings to track group changes before and after training and following fatigue and lengthening contractions.

Key words: Biodex, isotonic, reliability, fatigue, muscle damage, eccentric contractions.

Résumé : L'évaluation de la puissance mécanique au moyen d'appareils isokinétiques est, démonstration faite, très fiable. Toutefois, l'évaluation de la force au moyen d'appareils isotoniques et isokinétiques impose des contraintes mécaniques particulières qui, vraisemblablement, sollicitent diverses stratégies neuromusculaires. Dès lors, cette étude se propose de mesurer la fiabilité intra-évaluateur du test-retest (à sept jours d'intervalle) de l'évaluation de la vélocité de raccourcissement des muscles chargés au maximum et de la vélocité associée à la puissance mécanique des fléchisseurs dorsaux de la cheville, et ce, au moyen du dynamomètre Biodex en mode isotonique au (*i*) début et (*ii*) tout au long de la période de récupération consécutive à 150 contractions pliométriques de forte intensité. On calcule le coefficient de corrélation intraclasse ($ICC_{2,1}$) dont l'intervalle de confiance est de 95 % pour établir la fiabilité relative; la fiabilité absolue inclut l'erreur standard de mesure (TEM) et l'erreur standard de mesure exprimée en tant que coefficient de variation (TEM_{CV}). Vingt-quatre jeunes femmes et hommes participent à cette étude. On évalue la vélocité maximale de raccourcissement et la puissance au moyen d'une résistance équivalant à 20 % de la tension isométrique maximale (MVC) déterminée lors de deux séances d'évaluation intercalées d'une période de 7 jours. Les coefficients de corrélation intraclasse (ICCs) de la vélocité maximale de raccourcissement et de la puissance de pointe sont 0,93 et 0,98 respectivement. À la suite des contractions pliométriques, les ICCs révèlent une fiabilité élevée en ce qui concerne la vélocité maximale de raccourcissement et la puissance de pointe : 0,86 et 0,94, respectivement, ce qui suggère un même degré de fatigue manifestée au cours de ces deux journées. La fiabilité absolue de la vélocité maximale de raccourcissement et de la puissance de pointe se révèle aussi élevée. Lors de l'évaluation en mode isotonique de la vélocité associée à la puissance mécanique des fléchisseurs dorsaux de la cheville, on observe une fiabilité élevée au début et à la suite des contractions pliométriques épuisantes. La fiabilité élevée de ces mesures est encourageante; on peut donc utiliser le mode isotonique dans divers milieux d'évaluation pour dépister des modifications de groupe dans les conditions suivantes : avant et après un programme d'entraînement, après l'installation de la fatigue et après des contractions pliométriques.

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Mots-clés : Biodex, isotonique, fiabilité, fatigue, lésion musculaire, contractions pliométriques.

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Introduction

Reliability of isokinetic testing at various fixed angular velocities has been well established (Drouin et al. 2004; Feiring et al. 1990; Porter et al. 2002; Sole et al. 2007). However, when muscle power is tested isokinetically, shortening velocity is constrained artificially and does not provide a measure of muscle performance that replicates daily activities, in which the load is fixed and the velocity is unconstrained. A less common, but useful, method to determine power is to perform contractions under velocity-dependent conditions, whereby velocity is unconstrained and the contraction is performed at a predetermined load. The Biodex dynamometer (System 3, Biodex Medical Systems, Shirley, N.Y., USA) can be operated in the isotonic mode to allow for a fixed resistance (i.e., % maximal voluntary isometric contraction (MVC)) and a variable unconstrained angular velocity (Remaud et al. 2005, 2010) depending on the effort of the subject. Because these contractions involve the acceleration of a constant load rather than the measurement of torque produced at a constant velocity, this mode may serve as a better tool than isokinetic measures during clinical, athletic, and laboratory testing. Because of the recent increase in the use of the isotonic mode for baseline normative measures (McNeil et al. 2007; Valour et al. 2003), training (Remaud et al. 2010; Valour et al. 2004), and fatigue studies (Cheng and Rice 2009, 2010; Dalton et al. 2010; McNeil and Rice 2007; Power et al. 2010), it is essential to establish the day-to-day reliability and utility of this measure.

When testing participants using the isotonic mode of the Biodex dynamometer, the individual must first overcome the preset resistance throughout the range of motion, and any additional torque generated is translated into increases in velocity. Because of the inherent mechanical limitations of the dynamometer (it is unable to maintain an exact constant external load), these contractions are not strictly isotonic, and neither are they isoinertial because the load is fixed (mechanically) and is determined by the constant braking of the dynamometer (Jidovtseff et al. 2006). Therefore, we have chosen to refer to these contractions as "velocity dependent", in that these velocity-dependent movements involve an unconstrained angular velocity while the contraction is performed at a predetermined load (i.e., % MVC).

The determination of strength and power under isokinetic conditions has been shown to be reliable (intraclass correlation coefficients (ICCs)) in muscles about the ankle (0.61–0.96) (Holmbäck et al. 1999, 2001; Porter et al. 1996, 2002), knee (0.82–0.98) (Feiring et al. 1990; Pincivero et al. 1997, 2001; Sole et al. 2007), elbow (0.95–0.97) (Lund et al. 2005), and shoulder (0.60–0.95) (Malerba et al. 1993; Meeteren et al. 2002) joints, as well as during and following fatigue interventions (0.82–0.89) (Pincivero et al. 2001; Porter et al. 2002). However, isotonic and isokinetic testing involve different mechanical constraints that are likely to necessitate altered neuromuscular strategies to perform each movement effectively (Remaud et al. 2005, 2010). Thus, the reliability of the isotonic mode should be evaluated, and this may result in outcomes different from those achieved through isokinetic manoeuvres.

Fatigue, defined as any exercise-induced reduction in muscle performance, is task dependent and multifaceted (Enoka and Duchateau 2008); thus, it should be assessed using a multitude of tasks in addition to the most common, isometric strength (Cheng and Rice 2009). Isometric and isokinetic tasks utilize torque as the index of fatigue, whereas for velocity-dependent contractions, velocity is the underlying parameter that largely reflects changes in power over time. Isokinetic contractions are limited by a constant fixed velocity and provide limited information regarding fatigue-induced alterations in shortening velocity, which ultimately is the major determinant of power loss during daily activities with unconstrained velocities. It is of particular interest to explore the reliability of these measures to track group changes following a bout of unaccustomed lengthening contractions, which, in addition to muscle fatigue, are known to induce muscle damage (Clarkson and Hubal 2002; Morgan and Proske 2004) and require a prolonged recovery (Power et al. 2010) for the return of neuromuscular function. Because torque generation capacity is more impaired following damaging lengthening contractions than is loaded shortening velocity (Power et al. 2010), a moderately loaded contraction (i.e., 20% MVC) may provide a reliable day-to-day measure of muscle function following lengthening contractions such as those incurred during plyometric training.

The importance of accurately reproducing strength and power values is critical for the assessment of fatigue- and training-induced alterations in muscle function. Furthermore, the ankle dorsiflexors were chosen as the model of study because of this muscle group's consistently high voluntary activation with little familiarization (Klass et al. 2007). Therefore, the purpose of this investigation was to provide an initial determination of the day-to-day reliability of maximal shortening velocity and peak power in healthy young adults, using an isotonic testing mode, and to further the understanding of fatigue and recovery of shortening velocity following lengthening contractions.

Materials and methods

Experimental approach to the problem

A group of healthy young men and women performed dynamic contractions on a Biodex dynamometer using the "isotonic mode". Day-to-day reliability of velocity-dependent power (calculated at 20% MVC) was evaluated at baseline and following repeated high-intensity lengthening contractions. Data were collected at approximately the same time of day on 2 separate testing sessions 7 days apart. $ICC_{2,1}$ with 95% CIs were used to determine relative reliability, whereas absolute reliability measures included typical error (TEM) and typical error expressed as a coefficient of variation

(TEM_{CV}). Bland-Altman plots were constructed to provide a visual representation of systematic bias and variability.

Subjects

Twenty-four young men (n = 10; 25.6 ± 2.9 years) and women (n = 14; 25.3 ± 1.8 years) from the university population volunteered for this study. The mean height and body mass of the men and women were 176.4 ± 6.8 cm and 76.8 ± 7.8 kg, and 166.9 ± 6.6 cm and 61.5 ± 10.7 kg, respectively. Participants were recreationally active and free from musculoskeletal disorders and were not involved in systematic resistance training of the ankle dorsiflexors, nor were they competitive runners. This study received approval from the University of Western Ontario Review Board for Health Sciences Research Involving Human Subjects and conformed to the Declaration of Helsinki. Informed oral and written consent were obtained prior to testing. Participants were asked to refrain from strenuous exercise for 24 h prior to the day of testing and to not consume caffeine on the day of testing.

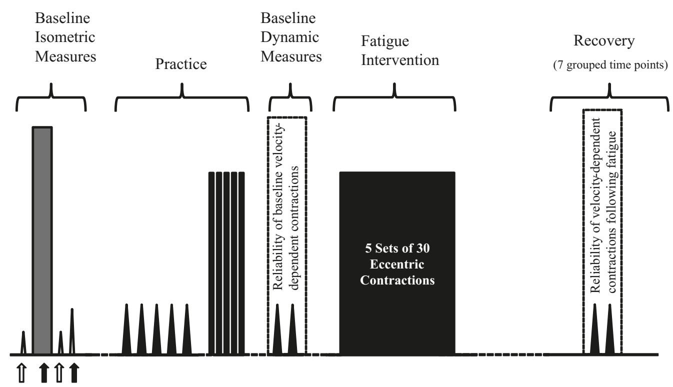
Experimental set-up

A Biodex multijoint dynamometer was used for testing, and calibration was verified according to Biodex System 3 guidelines. All dynamic contractions were performed in the isotonic mode. The right (dominant) foot was strapped tightly to the footplate, with the ankle in line with the rotational axis of the dynamometer. Extraneous body movements were minimized using no-elastic shoulder, waist, and thigh straps. Participants were positioned on the chair with hip and knee angles at ~110° and ~140°, respectively, and ankle angle at ~30° plantar flexion. All isometric contractions were performed at 30° of plantar flexion. Voluntary shortening contractions began from the plantar flexed position of 30° and ended at the neutral ankle angle (0°), thus moving through a 30° range of motion. Before the footplate moved during the velocity-dependent shortening contractions, participants had to overcome the preprogrammed resistance. The dynamometer absorbed this increase in applied torque, resulting in a directly proportional increase in angular velocity (Remaud et al. 2005).

Procedures

Velocity-dependent contractions were performed at 20% MVC. Pilot testing indicated that a 20% MVC load represents a moderate resistance in which the participant can perform fast shortening contractions without range of motion failure following high-intensity lengthening contractions. Three MVCs were performed for 3–5 s, with 3 min rest between all contractions (Fig. 1). Participants were provided visual feedback of the torque and were exhorted to perform maximally during all voluntary contractions. To ensure MVCs were maximal, voluntary activation was assessed using the modified interpolated twitch technique (Gandevia 2001). Contractions of the tibialis anterior were electrically evoked using a bar electrode held distal to the fibular head over the deep branch of the common peroneal nerve. A computer-triggered stimulator (model DS7AH, Digitimer, Welwyn Garden City, Hertfordshire, UK) was used with a setting of 400 V and a pulse width of 100 µs. The amplitude of the interpolated torque evoked during the peak plateau of the MVC (T_s) was compared with a resting twitch doublet

Fig. 1. Schematic diagram of experimental protocol. Baseline measures, a fatigue intervention, and recovery measures were performed in the same order during 2 sessions separated by 7 days. Day-to-day reliability analyses were performed on peak velocity and power for the baseline velocity-dependent contractions and the recovery response of these measures following the fatigue intervention. Grey bars are maximal voluntary isometric contractions (MVC). Open triangles are electrically evoked contractions (twitch and twitch doublet). Open arrows indicate the stimuli of the electrically evoked twitches, and filled arrows indicate the stimuli of the electrically evoked doublets. Filled profiles are dynamic contractions: fast velocity-dependent shortening contractions at 20% MVC (triangles) and dynamic lengthening contractions at 80% MVC (rectangles). Recovery time points were 30 s and 2, 5, 10, 15, 20, and 30 min.



torque evoked when the muscle was relaxed fully ~1 s after the MVC attempt (T_r). If the superimposed twitch doublet torque amplitude was visible during the MVC, the participant was encouraged to perform an additional attempt until there was indeed minimal voluntary activation failure. Percentage voluntary activation was calculated as follows: voluntary activation (%) = $(-T_s/T_r) \times 100$. Values from the MVC with the highest torque amplitude were used for data analysis.

Once MVC torque was determined to be maximal, the dynamometer was switched from the isometric to the isotonic mode, and a load equal to 20% MVC was programmed. The dynamometer was programmed to allow the footplate to return to 30° of plantar flexion at the end of each shortening voluntary contraction while the participant relaxed fully. Familiarization with these "fast" shortening contractions involved participants performing several (typically 5) velocity-dependent shortening contractions until a stable baseline value was obtained (no change in maximal shortening velocity). To ensure a maximal effort (peak velocity) contraction, all participants were instructed to move the load "as hard and as fast as possible throughout the entire range of motion". To assist participants in reaching their maximal shortening velocity, visual feedback of the velocity profile was provided via a computer monitor, and a horizontal cursor was positioned at the previous personal best attempt. Participants rested for 3 min and then performed 2 consecutive contractions, and the faster was used to establish baseline values for maximal shortening velocity and peak power.

Lengthening contraction intervention

Because many natural movements are composed of isometric, shortening, and lengthening phases, we challenged the system with an understudied but important dynamic task of lengthening contractions to explore reliability following fatigue in relation to velocity and power, and also uniquely during a period of recovery. Participants performed 5 sets of 30 lengthening dorsiflexion contractions with a load of 80% MVC, and each set was separated by 30 s. The contractions started at the neutral ankle angle (0°) and ended at 30° plantar flexion, thus moving through a 30° range of motion. Participants were provided with visual feedback of velocity and were instructed to resist while lowering the footplate through the 30° range of motion over a 1-s period (~30°·s^{-1}). The foot was then returned to the neutral ankle position by the investigator over a period of 2 s. Following task completion on both day 1 and day 2, absolute peak velocity of the shortening contractions was determined from 2 contractions performed at each of 7 time points throughout recovery, at 0.5 min, 2 min, 5 min, 10 min, 15 min, 20 min, and 30 min (Fig. 1). The absolute peak velocity values from each of the 7 recovery time points from day 1 and 2 were used to assess the reliability of the overall recovery response to the lengthening contraction protocol (see Statistical analyses section for specific measures) (Portney and Watkins 2000), which allowed for a comprehensive analysis of the reliability of recovery following the intervention of lengthening contractions.

Data reduction and analysis

Torque, position, and velocity data were sampled at 100 Hz and converted to digital format using a 12-bit analog-to-digital converter (model 1401 Plus, Cambridge Electronic Design, Cambridge, UK). Spike 2 software (Cambridge Electronic Design) was used to determine offline values for MVC torque, and voluntary maximal shortening velocity. Power was calculated as the product of torque (N·m) and the peak shortening velocity (rad·s^{-1}) of the faster of 2 contraction attempts (as described above).

Statistical analyses

All statistical analyses were performed using SPSS software, version 16 (SPSS Inc., Chicago, Ill., USA) and Microsoft Excel 2007 (Microsoft, Seattle, Wash., USA).

Paired *t* test analysis between day 1 and day 2 was performed to establish whether reproducibility bias was present for baseline measures. Reliability of baseline and recovery measures was assessed using the following statistical analyses: Bland–Altman plots were constructed to provide a visual representation of systematic bias and variability (Atkinson and Nevill 1998) by plotting the difference between day 1 and day 2 against the individual mean of day 1 and day 2 using either peak velocity or power at baseline and following the lengthening contractions. Reliability of maximal shortening velocity and peak power were assessed using the $ICC_{2,1}$, which is based on a repeated-measures analysis of variance (ANOVA) with testing session as the independent variable (Shrout and Fleiss 1979). The first subscripted number denotes the model (e.g., 2), selected because it is based on repeated-measures ANOVA, during which all participants are assessed by the same rater. The second subscripted number signifies the form, using either a single score (1) or the mean of several scores (2). The scores were peak absolute values (Shrout and Fleiss 1979). This model takes into account differences among participants and testing sessions, and error variance. Therefore, $ICC_{2,1}$ with 95% CIs were used to determine the relative reliability across the 2 testing sessions of peak shortening velocity and power at baseline and following lengthening contractions. Measures of absolute reliability include TEM, TEM_{CV}, and the limits of agreement (LOA), reflecting 95% probability limits between which the difference scores of day 1 and 2 should fall. The TEM was calculated as the SD of the difference score between the 2 days, divided by the square root of 2. The coefficient of variation of the TEM was calculated as the TEM divided by the average of all trials, multiplied by 100 (Hopkins 2000). The LOA was calculated as the mean difference between the 2 days ± 1.96 × SD of the difference between the 2 days. α was set at 0.05, and Table 1 data are presented as means ± SD.

Table 1. Absolute baseline measures.

	MVC (N·m)	Velocity (°·s^{-1})	20% MVC (N·m)	Power (W)
Test day 1	41.4±11.5	143.2±18.6	8.2±2.2	21.1±8.4
Test day 2	41.2±11.5	143.4±16.8	8.3±2.2	21.2±7.5

Note: Data are presented as means ± SD. MVC, maximal voluntary isometric contraction.

Results

Among participants, MVCs ranged from 24 to 66 N·m, whereas individual scores were highly reproducible day to day, thus resulting in similar 20% loads (8.2 ± 2.2 and 8.3 ± 2.2 N·m) with which the loaded velocity-dependent shortening contractions were performed. The means and SDs for MVC, maximal shortening velocity, and peak power on day 1 and day 2 are presented in Table 1. There were no significant differences between day 1 and day 2 for any of these measures ($p > 0.05$). In addition, voluntary activation was near maximal at baseline (99% ± 1%) and following the lengthening contractions (96% ± 5%; 95% ± 6%) on both days ($p > 0.05$).

ICCs were calculated separately for men and women for maximal shortening velocity and power at baseline. However, ICCs were not different between the sexes for velocity (0.93 (men), 0.94 (women)) or power (0.97 (men), 0.98 (women)). Thus, data were pooled to represent the reliability of velocity and power for both men and women for all subsequent analyses.

The differences between test day 1 and test day 2 for maximal shortening velocity and peak power at baseline and following lengthening contractions are plotted against the average of the 2 testing sessions for each individual (Fig. 2). The results from the Bland–Altman plots show the mean bias to be positive and relatively small for velocity and power measures, indicating that values were slightly higher on day 2, with fatigue data showing a greater bias towards a positive difference between the 2 testing sessions. For all Bland–Altman plots, the 95% LOA were symmetric around the zero line, with a greater tendency towards asymmetry for the fatigue data.

Despite fluctuations in mean bias, the ICCs for maximal shortening velocity and peak power at baseline (presented in Table 2) were classified as “high” (Portney and Watkins 2000). The pooled recovery data over 30 min for maximal shortening velocity and peak power following the lengthening

Fig. 2. Bland–Altman plots of maximal shortening velocity (°·s^{-1}) (*a*) and peak power (W) (*b*) at baseline and following the fatigue intervention (*c* and *d*), respectively, for women (open circles) and men (closed circles). The horizontal lines represent the mean bias (dotted line) and upper and lower 95% limits of agreement. The *x* axis is the mean value of day 1 and day 2, and the *y* axis is the difference score of day 2 – day 1.

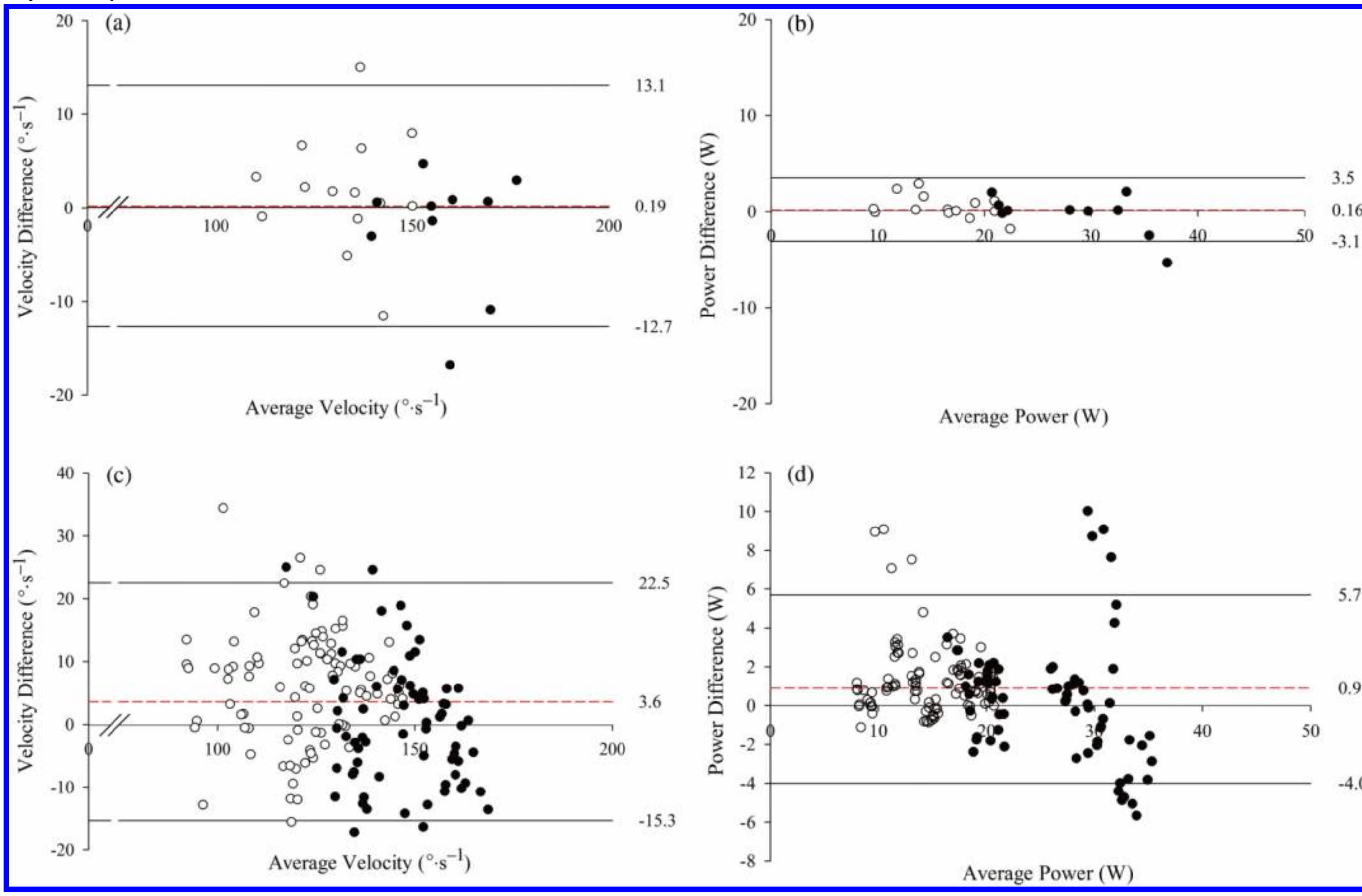


Table 2. Reliability statistics for maximal shortening velocity and peak power.

	Baseline		Recovery	
	Velocity	Power	Velocity	Power
Mean difference	0.19	0.16	3.60	0.90
Between measurement (*p* value)	0.89	0.64	n/a	n/a
Intraclass correlation coefficient	0.93	0.98	0.86	0.94
Lower confidence limit	0.85	0.95	0.82	0.93
Upper confidence limit	0.97	0.99	0.90	0.96
Typical error	4.66	1.19	6.80	1.80
Typical error as a coefficient of variation	3.25	5.63	5.20	8.70

Note: Between-measurement *p* values are not reported for day-to-day recovery data because the data were pooled over the testing sessions and analyzed as a time effect of the fatigue intervention.

contractions also displayed high intraclass correlations for maximal shortening velocity and peak power.

Measures of absolute reliability for maximal shortening velocity and peak power are presented in Table 2. The TEM and coefficient of variation associated with shortening velocity were 4.66°·s^{-1} and 3.25%, respectively. The TEM and coefficient of variation associated with peak power were 1.2 W and 5.63%, respectively. Following the lengthening contractions, the TEM associated with shortening velocity was 6.80°·s^{-1} and the coefficient of variation was 5.20%. The TEM associated with peak power following the lengthening contractions was 1.8 W and the coefficient of variation was 8.7%.

Discussion

This study analyzed the day-to-day reproducibility of maximal shortening velocity and velocity-dependent power with a load set at 20% MVC in healthy young adults before and after an intervention of repeated high-intensity lengthening contractions. Our findings demonstrate relative reliability (ICCs) to be "high" at baseline and following lengthening contractions. Absolute reliability, as assessed via the coefficient of variation of the TEM for maximal shortening velocity and peak power, resulted in errors of ~3% and ~9% at baseline and following the lengthening contractions, respectively. As suggested by Portney and Watkins (2000), intraclass correlations >0.75 are considered to have good reliability. In this study, ICC confidence intervals for velocity and power at baseline ranged from 0.85 to 0.97 and 0.95 to 0.99, respectively. As well, following the lengthening contractions, we obtained ICC confidence intervals ranging from 0.82 to 0.90 and 0.93 to 0.96 for velocity and power, respectively, indicating high reliability. The high reliability of this measure is encouraging and suggests that the isotonic mode can be used in various settings to track group changes, such as before and after training and following fatigue and lengthening contractions.

This study reported TEM and TEM_{CV}; these statistics provide an absolute and generalizable measure, respectively, for comparisons of reliability among individuals of different strength and power. TEM provides a reliability statistic free from the influence of correlations; in addition, TEM_{CV} serves as a dimensionless measure, which allows for comparison across reliability studies using different testing protocols, participants, and measurement tools (Hopkins 2000). Here, lower values for TEM and TEM_{CV} indicate high reliability. Velocity measures resulted in a TEM of $4.66°{\cdot}s^{-1}$, and a TEM_{CV} of 3.25%, which suggests that one would need a signal-to-noise ratio greater than $\sim 5°{\cdot}s^{-1}$ and a 3.25% difference to observe a value that would not be associated with systematic error. Power measures resulted in a TEM of 1.19 W and a TEM_{CV} of 5.63%, which suggests that one would need a signal-to-noise ratio >1.19 W and a difference of 5.63% to observe a value that would not be associated with systematic error. Visual analysis of the graphs and interpretation of the Bland–Altman analysis showed the mean absolute scores for maximal shortening velocity and power at baseline to be stable across day 1 and day 2. The mean bias for velocity ($0.19°{\cdot}s^{-1}$) and power (0.16 W) at baseline suggests that there was no practice–learning effect from performing the previous bout. Adding the element of repeated lengthening contractions over time allows for potentially more error to affect the true score. There was, however, only a mean bias of $3.6°{\cdot}s^{-1}$ and 0.87 W for velocity and power, respectively, following the lengthening contractions (Fig. 2). The positive mean bias on day 2 following the lengthening contractions suggests that there was less impairment in shortening velocity and power; thus, individuals may have benefited slightly from the previous experience, such that the muscle may have adopted a protective mechanism leading to less impairment in neuromuscular function during the second day of testing, commonly known as the "repeated bout effect" (Clarkson and Hubal 2002; Nosaka et al. 2001). For example, the muscle may have adapted to the previous bout of lengthening contractions with the addition of more sarcomeres in series (Morgan and Proske 2004), which "protected" the muscle from subsequent damage during the second testing day 1 week later. However, the baseline values for maximal shortening velocity and peak power were highly consistent across days (Fig. 2), suggesting that the muscle had adequate time to recover from the previous bout of lengthening contractions.

In the present study, the ICC statistics were higher for power than for velocity. This may be attributed to "normalization" of shortening velocity to a percentage of one's MVC (power (W) = 20% MVC (N·m) × velocity ($rad{\cdot}s^{-1}$)). Reliability methods based on correlation coefficients, such as ICC, provide a measure of relative reliability. However, unlike measures of absolute reliability, these reliability statistics are influenced by the range of values measured and give no indication of actual measurement values or systematic variability within the measure itself (Hopkins 2000). Here, the ICC for maximal shortening velocity was 0.93, whereas the TEM_{CV} was 3.25%. Although power had a higher ICC of 0.98, it was associated with more measurement error (5.63%), thus emphasizing the need for several statistical measures to evaluate reliability effectively. Using the isotonic mode, in which power is calculated as a percentage of MVC, the additional error can be attributed to day-to-day variability of the MVCs and hence emphasizes the importance of proper control measures to ensure that a suitable maximal isometric effort is obtained prior to isotonic testing.

When performing velocity-dependent contractions, strict care ought to be taken to ensure high reliability. First, the process of obtaining the isometric MVC must be controlled to achieve a maximal value; depending on the muscle group, this may require multiple familiarization attempts (Gandevia 2001; Jakobi and Rice 2002). The current study investigated ankle dorsiflexors because of the consistently high voluntary activation levels reported for this muscle group (Klass et al. 2007). Second, to obtain a maximal effort (peak velocity) during the velocity-dependent contractions and reduce the "learning effect", participants were required to reach a consistent peak velocity (no change during 5 successive attempts) before performing baseline attempts. A fast, maximal effort can be achieved by providing the participant with visual feedback of the velocity profile and positioning a horizontal cursor at a previous personal best. These considerations help minimize the likelihood of introducing systematic error into the measurement and ensure high reliability.

Holmbäck et al. (1999) investigated the isokinetic reliability of the ankle dorsiflexors of young men and women across a range of velocities ($30–150°{\cdot}s^{-1}$). The ICCs for peak torque when the participants were tested at 120 and $150°{\cdot}s^{-1}$ (similar to our isotonic velocities) ranged from 0.78 to 0.80, with a coefficient of variation of ~13% and a trend of increasing measurement error with increasing velocity. This is not surprising based on a study of the mechanical reliability of the Biodex (Drouin et al. 2004), which showed higher reliability values associated with slower isokinetic velocities. In our study, we found that high reliability and minimal measurement error were associated in determining power before and after lengthening contractions using the isotonic mode. But it is unknown whether such reliability would be similar in young adults when performing isotonic contractions at other relative workloads, which may dictate a faster or slower angular velocity or place a greater or lesser demand on the rate of torque development. Furthermore, with the increasing recognition of the isotonic mode for neuromuscular testing (Cheng and Rice 2009, 2010; Dalton et al. 2010; McNeil and Rice 2007; Power et al. 2010), reliability should be evaluated in other populations, such as elite athletes, individuals with athletic injuries, or those with musculoskeletal disorders, to ensure the utility of this testing mode.

These measures of relative and absolute reliability indicate that velocity-dependent power is sufficiently reproducible when assessing baseline muscle characteristics (as in the case of a training intervention) and recovery following an intervention consisting of lengthening contractions. Whether one accepts these values depends greatl on the precision one requires to observe a meaningful difference. When investigating fatigue-induced changes following an exercise intervention or over the course of a training study, these day-to-day error fluctuations are relatively small and should provide reliable measures. To reduce the chance of introducing systematic error into the measurement when testing under unconstrained velocity conditions, participants must be highly motivated and able to maintain high, or at least consistent, voluntary activation of the muscle group involved, and for some clinical populations this may require multiple practice contractions or separate familiarization days.

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