Test-retest reliability of muscular performance tests and compression garment interface pressure measurements: A comparison between consecutive and multiple day recovery

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Abstract

Whilst much research has been carried out on the use of compression garments for muscular recovery, reliability data on muscular performance and compression pressure measurements are lacking in non-resistance trained populations. Therefore, the between-day and within-session reliability of garment interface pressure measurements and lower-limb maximal voluntary contraction forces was assessed in non-resistance trained males and compared between groups testing on consecutive (CONSEC, n = 12), or non-consecutive days (≥ 48 h; REC, n = 12). Interface pressures were measured with a pneumatic sensor, before knee extension performance of the dominant leg (isometric, $60^{o}\cdot s^{-1}$, $120^{o}\cdot s^{-1}$ and $180^{o}\cdot s^{-1}$) and 6 s cycle sprint performance were assessed. Peak isometric and isokinetic forces at $60^{o}\cdot s^{-1}$ and $120^{o}\cdot s^{-1}$ declined between days in CONSEC ($p < 0.05$; CV 5.1 - 6.6%), but not in REC ($p > 0.05$; CV 3.5 – 9.4%). Cycling peak power increased between days, regardless of group ($p = 0.014$; CV 4 – 4.8%). Interface pressures were similar between days and groups, but highly variable ($p > 0.05$; CV 6.8 – 17%). Familiarization with isometric and isokinetic testing may be unnecessary in non-resistance trained males. Strength losses resulting from performance tests should be considered when assessing recovery on consecutive days. Conversely, 6 s sprint cycle testing required at least one familiarization session. Interface pressure measurements should be reported alongside reliability coefficients, while further research is needed to quantify the deterioration of interface pressures in relation to the reliability of these measurements when compression garments are worn for multiple days' recovery.

Introduction

The term "recovery" describes the rate and magnitude with which exercise performance is re-established following exercise [1]. The mechanisms involved in recovery, and therefore the effectiveness of particular interventions, are highly specific to the duration, intensity and modality of a specific exercise challenge [2]. For example, whilst the deleterious effects of substrate depletion and metabolite accumulation may impair performance for minutes or hours [3, 4], exercise-induced muscle damage (EIMD) may reduce muscle function for over a week [5, 6]. Accordingly, much research has been carried out on potential strategies to enhance recovery from EIMD [5-7]; a term used to describe the disruption of myofibres, which is commonly caused by eccentric (i.e., muscle lengthening) contractions.

As researchers commonly assess muscular recovery over the 2 – 5 days following EIMD [5-7], it is imperative that the performance measures employed demonstrate acceptable between-day reliability [8]. However, whilst recovery from EIMD is assessed from changes in isometric and isokinetic performance [5-7], these exercise modalities are known to elicit damage [9, 10]. Furthermore, the reliability of a test may be highly population-specific [8] and there is little published isokinetic and isometric reliability data from non-resistance trained participants [9, 11]. The effects of consecutive daily testing on reliability have not been established, which is particularly pertinent given the increased susceptibility of non-resistance trained participants to EIMD [5, 6]. Research is therefore required to establish the effects of isometric and isokinetic testing on next day performance and between-day reliability in non-resistance trained participants.

The use of compression garments (CG) has been studied extensively for exercise recovery, with evidence demonstrating particular benefits for the recovery of strength and power performance following EIMD [12]. Compression garments appear to be effective for recovery from EIMD in both the upper and lower limbs following a range of laboratory and field-based exercise protocols, in participants ranging from healthy adults to competitive athletes [12-16]. However, conclusions are still complicated by contradictory evidence [17, 18], with neither the mechanisms responsible for recovery, nor evidence of a clear dose-response relationship yet established [17]. This uncertainty may be, at least in part, due to the scarcity of trials that have adequately characterized the garments used. Many studies to date have failed to report the pressures exerted by CG, or cited estimated values [12-14].

If the benefits of CG are indeed related to applied pressures [16], this inaccuracy may explain much variation between trials. Furthermore, although portable pneumatic pressure monitors have become available over the last decade, there are issues of validity and reliability in an applied setting. "Interface pressures" (taken at discrete points at the skin-garment interface) vary with sensor positioning [19], participant anthropometry [20], and the manner in which the garments are put on [21]. Considering that CG are often worn for multiple days over compression studies, but are removed and replaced to allow participants to wash [15, 16], there is a need to quantify the reliability of CG pressure measurements in this context. These data would better contextualize reported compression pressures, particularly when researchers are comparing the benefits of different garments [16].

Given the paucity of current literature, the aims of the present study were twofold: 1) to quantify the effects of a typical muscle damage testing battery on the magnitude and reliability of next day performance compared to tests separated by ≥ 48 h recovery; and 2) to measure and compare the magnitude and variability of garment pressure measurements between days and within sessions.

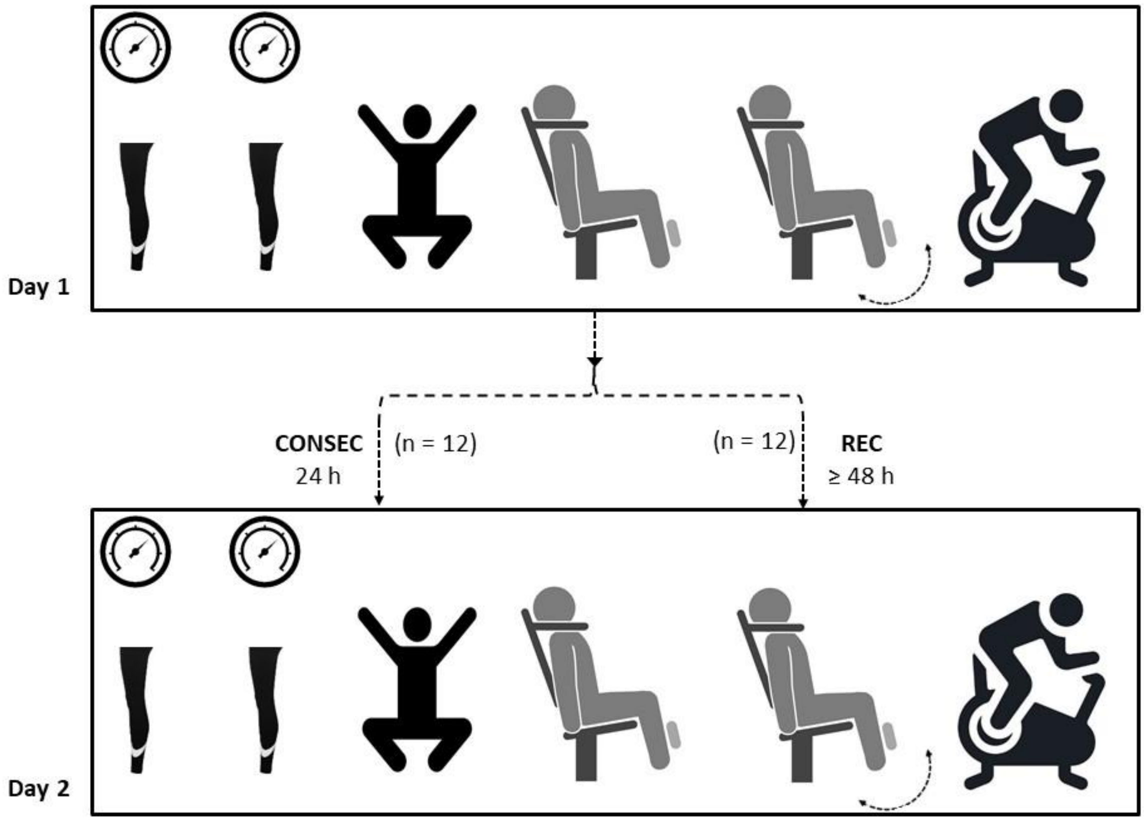
These data will allow researchers to more accurately quantify muscular recovery, and to better understand the variability of pressures applied by CG.

Methods

Design

Outcome measures were assessed using a mixed-measures (group x day) design (Figure 1). Within-participant changes were compared at the same time of day (± 2 h) over two days (D1 and D2), between groups completing tests on consecutive (CONSEC) and non-consecutive days (REC). Recovery in REC ranged from a minimum of 48 h, a duration sufficient for recovery from isometric exercise [11], to an upper limit of 14 days, to control for possible changes in training status [22]. Assessments were carried out in standard laboratory conditions, with participants requested to arrive in a hydrated state, and to record food and fluid intake on D1 for replication on D2.

Figure 1 Study Design



= Compression pressure testing = Standardized warm-up = Maximal voluntary isometric contraction

= Maximal voluntary isokinetic contractions (60°·s-1 120°·s-1 and 180°·s-1) = 6 s Sprint cycle test

CONSEC (n = 12) = tested on consecutive days; REC ≥ 48 h recovery (n = 12, range: 2 – 14 d). All Performance tests were taken as the best of three attempts (90 s recovery) except for isokinetic tests which were done consecutively. Additional tests were performed if performance had not plateaued by the 3rd attempt.

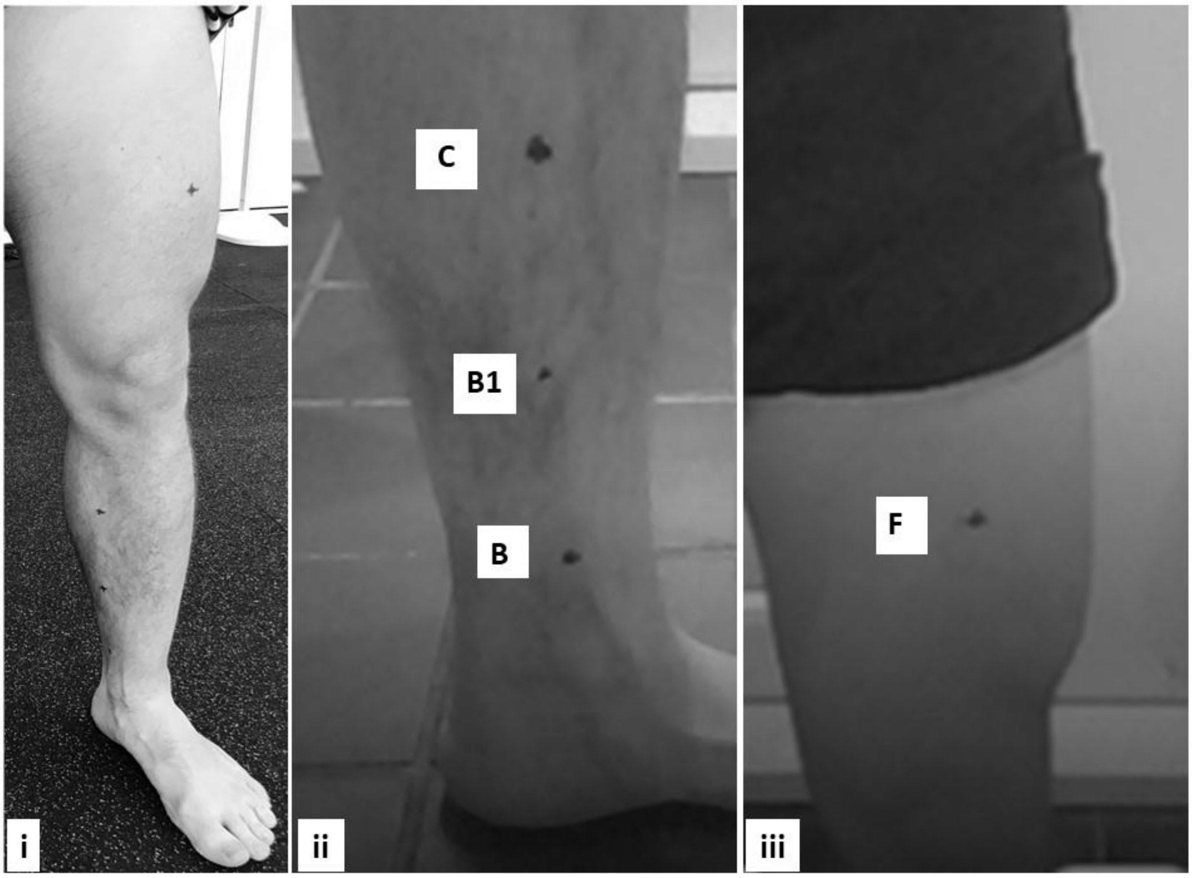
Participants

Following institutional ethics approval (Ref P93660), two groups of 12 physically active males (18 – 45 y) were recruited, in accordance with the STROBE statement and the treaty of Helsinki. Participant characteristics for REC were: 26.5 ± 6.8 y, 75.6 ± 9.8 kg, 1.77 ± 0.06 m, and 28.5 ± 6.7 y, 77.0 ± 7.2 kg, 1.79 ± 0.07 m for CONSEC. An upper limit of 45 years old was chosen as is common in research on muscle function [23, 24], due to the effects of aging on muscle protein metabolism [24]. Participants were unaccustomed (> 6 months) to lower body resistance exercise, but were required to be undertaking the weekly equivalent of 150 min low intensity activity or 75 min vigorous exercise in accordance with physical activity guidelines [25]. A sample of 12 was deemed to be sufficient to detect a (moderate) intraclass correlation coefficient (ICC) value above 0.6 from two observations [26], as calculated from recent findings [16].

Procedures

On arrival, body mass was measured in minimal clothing (875 Class III scale, seca, Birmingham, UK). Stature was then recorded (213 Portable Height Measure, seca, Birmingham, UK), before participants lay supine for 10 min to equilibrate body water between compartments [27]. Mid-thigh girth and calf circumference were measured to allow medical grade CG to be fitted to manufacturer specifications (Duomed soft thigh length compression stockings, Medi UK Ltd., Hereford, UK) [19]. British class II graduated stockings (designed to apply 18 – 24 mmHg at the ankle, reducing by 50% at the groin) were used in line with recent research suggesting that such garments are effective for recovery [16]. Subsequently, medical grade garments were measured for applied pressures in the standing position (Picopress, Microlab, Padua, Italy) according to consensus guidelines [19] (Figure 2). The garments were being used as part of a larger study on exercise recovery, and therefore may have been worn previously. However, all garments were washed between participants, which is known to restore CG elasticity [28]. A permanent marker was used to mark each point on the leg for subsequent identification, and pressures measured twice on each visit. Garments were worn for measurements only (~ 10 min per visit), being removed before exercise, between measurements and between days. Due to the overlap between limb circumference measurements recommended for each given size, if CG did not provide 14 mmHg at the thigh for the first measurement (a proposed pressure threshold in the exercise literature [16, 29]) then the next smallest garment was provided. Small, medium, and large sizes were used, with stockings pulled up to the groin and visually checked for uniform tension and a lack of folds before measurements taken. The accuracy of the Picopress was verified against a mercury sphygmomanometer as a criterion measure when pressures were applied with a rapid cuff inflation device (Hokanson Rapid Cuff Inflator; Hokanson Inc., Belleview, WA, USA) over a cylindrical column.

Figure 2 – Compression testing sites



i. Whole leg; ii. Lower leg; iii. Thigh; B = B point (narrowest point of the ankle; C = C point (greatest calf circumference); B1 = B1 point (equidistant between B and C [41]); F = mid-thigh skinfold site (half-way between the inguinal fold and patella).

A standardised warm-up was then completed, consisting of 3 min cycling at 100 W (Wattbike Pro, Wattbike Ltd., Nottingham, UK), followed sequentially by 10 repetitions of squats, lunges (alternate legs), and countermovement jumps. Participants were then assessed for peak isometric and isokinetic force of the knee extensors, with the dynamometer positioned according to manufacturer instructions (KinCom, Chattanooga, TN, USA – 100 Hz). Each test was performed after three repetitions at 50% maximal effort to aid familiarization and muscular potentiation. Following warm-up, maximal voluntary isometric contraction (MVIC) of the knee extensors was assessed at 85° knee flexion. The dominant limb was secured at the thigh and a seat-belt was fastened across the chest, with participants not permitted to grip the sides of the chair to minimize the contribution of the upper body. Peak force was recorded for each of three attempts separated by 90 s, and the greatest value used for between-day comparisons [15, 16]. Subsequently, peak force of isokinetic contractions was assessed at $60^{o}\cdot s^{-1}$ $120^{o}\cdot s^{-1}$ and $180^{o}\cdot s^{-1}$ (IKD60, IKD120, IKD180), with three consecutive contractions performed at each velocity between 85° and 15° of knee flexion. Following strength assessments, peak power output (W_{pk}) in a 6 s cycle sprint test was assessed [30], with 90 s recovery provided between all trials. A minimum of three repetitions was completed on each day for all tests. However, if a plateau had not been reached by the third trial - defined from an increase over the final two attempts resulting in a coefficient of variation (CV) > 5% - additional repetitions were performed until familiarization and the final value recorded. Where performance declined over the first two trials, then trial three was compared to trial one. On day two, familiarization was deemed incomplete if variation > 5% was observed compared to both the maximum value from day one, and from the previous repetition. The number of trials required for complete familiarization was therefore determined for each test, for each participant over the two days.

Statistical analysis

Residuals were assessed for normality by visually inspecting Q-Q plots, then using the Shapiro-Wilk test. Changes in peak force were assessed using a three-way (repetition × day × group) mixed-model analysis of variance (ANOVA) (SPSS Statistics 24, IBM, New York, USA), while between-day changes in performance were calculated from a two-way ANOVA on peak values. Post-hoc comparisons were made where a day x group interaction was observed, and adjusted for multiple comparisons. Within-session and between-day reliability were described from CVs calculated from typical error, and expressed as both raw and percentage values [31]. Additionally, ICC values were derived, and 95% limits of agreement calculated between days [8]. Alpha was set *a priori* at 0.05.

Results

The mean number of repetitions until familiarization did not differ between groups for any measure ($p > 0.05$), and was observed as follows (mean ± SD): MVIC = 2 ± 1; IKD60 = 2 ± 1; IKD120 = 2 ± 1; IKD180 = 2 ± 2; W_{pk} = 3 ± 2. In total, five participants completed additional repetitions on at least one isometric/isokinetic test (1 REC, 4 CONSEC). Two participants completed an additional three MVCs on D1, while two completed an extra six, resulting in 13 ± 2 repetitions. Only one participant improved with additional repetitions ($120^{o}s^{-1}$), peak force being reached on the fourth attempt. On D2, two participants (1 REC, 1 CONSEC) completed an additional three repetitions, resulting in a mean average of 12 ± 1 MVICs. Four participants (2 REC, 2 CONSEC) required additional attempts on D1 to reach W_{pk}, with a further two completing additional attempts on D2 (1 REC, 1 CONSEC). One participant (CONSEC) improved with an additional repetition (D1, familiarized after the fourth attempt).

Peak MVIC force did not differ between repetitions (F = 0.517, p = 0.6), while within-day reliability in both groups was described by CV and ICC values ≤ 6%, and ≥ 0.8, respectively (Table 1). Between-day reliability was also similar between groups (Table 1). However, maximal performance (best of three repetitions) declined significantly between days, with post-hoc tests identifying a decline in CONSEC only (Table 1). Peak force increased between repetitions for all isokinetic tests (from p < 0.001 to p = 0.002), within-day reliability being characterized by CV and ICC values of 5.4 – 10.6% and 0.67 - 0.83 respectively, across the three testing velocities (Table 1). Group x day interactions were observed using three-way ANOVA at both $60^{o}s^{-1}$ (F = 4.634, p = 0.043) and $120^{o}s^{-1}$ (F = 11.403, p = 0.003), with (mean) peak force declining between days in CONSEC only (Table 1). Maximal isokinetic performance at these velocities also declined between days in CONSEC, as described by two-way ANOVA (Table 1). Between-day reliability for peak isokinetic forces ranged from 3.5 – 9.4% in REC and 5.1 – 6.6% in CONSEC (Table 1). Sprint cycle W_{pk} improved between repetitions (p < 0.001) similarly on both days, with greater mean peak values on D2 (F = 13.6, p < 0.001). Peak values also improved between days in both groups (Table 1).

Picopress pressure measurements were highly correlated with those of the mercury sphygmomanometer when measured on over a cylindrical column from 10 – 30 mmHg (r = 0.99, p < 0.001), with between-day reliability (CV) < 1 mmHg (2.2%). Between-day reliability of CG pressures (Table 2) ranged from CV = 6.8% at the thigh to 17% at the ankle (1 – 3 mmHg). In CONSEC, ICCs ranged from 0.63 to 0.8. Results were similar in REC, except at the thigh where a between-day ICC value of 0.39 was observed (CV = 12.6%). Between-participant variation (SD) in pressure ranged from 5 mmHg at the thigh (44%) to 11 mmHg at the B1 point (50%).

Table 1. Between-day and within-session variation in muscular performance measures

Test	REC					CONSEC					Two-way		
	Within-session (repetitions)			Between-day		Within-session (repetitions)			Between-day		ANOVA (peak)	F	*p*
MVIC	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	-18	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	-67	**Group**	0.18	0.676
	2-1 =	5.1%	5.4%	**Mean diff$_{bd}$ (%):**	-2.7%	**2-1 =**	7%	4.2%	**Mean diff$_{bd}$ (%):**	-10%	**Day**	15.69	< 0.001*
	3-2 =	7.3%	4.5%	**ULOA$_{bd}$ (N):**	52	**3-2 =**	5.3%	2.8%	**ULOA$_{bd}$ (N):**	52	**Group x Day**	5.252	0.032*
	3-1 =	6.8%	6.4%	**LLOA$_{bd}$ (N):**	-121	**3-1 =**	7.7%	4.4%	**LLOA$_{bd}$ (N):**	-168			
	CV$_{ws}$ =	6%		**CV$_{bd}$ =**	6%	**CV$_{ws}$ =**	5.5%		**CV$_{bd}$ =**	5.7%	**Post hoc:**		
	ICC$_{ws}$ =	0.8		**ICC$_{bd}$ =**	0.83	**ICC$_{ws}$ =**	0.83		**ICC$_{bd}$ =**	0.73	REC D2-D1		0.251
											CONSEC D2-D1		<0.001*
IKD60	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	16	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	-54	**Group**	0.001	0.97
	2-1 =	12.5%	8%	**Mean diff$_{bd}$ (%):**	2.6%	**2-1 =**	12.3%	9.5%	**Mean diff$_{bd}$ (%):**	-9%	**Day**	2.115	0.16
	3-2 =	6.3%	6%	**ULOA$_{bd}$ (N):**	81	**3-2 =**	8.1%	10.1%	**ULOA$_{bd}$ (N):**	44	**Group x Day**	7.024	0.015*
	3-1 =	10.5%	6.6%	**LLOA$_{bd}$ (N):**	-142	**3-1 =**	13.1%	11.0%	**LLOA$_{bd}$ (N):**	-140			
	CV$_{ws}$ =	8.9%		**CV$_{bd}$ =**	9.4%	**CV$_{ws}$ =**	10.6%		**CV$_{bd}$ =**	5.1%	**Post hoc:**		
	ICC$_{ws}$ =	0.77		**ICC$_{bd}$ =**	0.77	**ICC$_{ws}$ =**	0.67		**ICC$_{bd}$ =**	0.68	REC D2-D1		0.407
											CONSEC D2-D1		0.008*
IKD120	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	17	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	-27	**Group**	0.537	0.471
	2-1 =	6.7%	5.9%	**Mean diff$_{bd}$ (%):**	3%	**2-1 =**	7.0%	8.3%	**Mean diff$_{bd}$ (%):**	-5.3%	**Day**	0.404	0.532
	3-2 =	4.6%	2.4%	**ULOA$_{bd}$ (N):**	27	**3-2 =**	2.4%	4.3%	**ULOA$_{bd}$ (N):**	48	**Group x Day**	7.685	0.011*
	3-1 =	7.2%	6.2%	**LLOA$_{bd}$ (N):**	-37	**3-1 =**	7.1%	8.8%	**LLOA$_{bd}$ (N):**	-122			
	CV$_{ws}$ =	5.5%		**CV$_{bd}$ =**	3.5%	**CV$_{ws}$ =**	7.0%		**CV$_{bd}$ =**	6.6%	**Post hoc:**		
	ICC$_{ws}$ =	0.83		**ICC$_{bd}$ =**	0.87	**ICC$_{ws}$ =**	0.77		**ICC$_{bd}$ =**	0.74	REC D2-D1		0.145
											CONSEC D2-D1		0.025*
IKD180	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	6	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	-27	**Group**	0.644	0.431
	2-1 =	6.1%	5.5%	**Mean diff$_{bd}$ (%):**	1.2%	**2-1 =**	12.6%	5.6%	**Mean diff$_{bd}$ (%):**	-5.6%	**Day**	1.124	0.3
	3-2 =	4.3%	3.7%	**ULOA$_{bd}$ (N):**	54	**3-2 =**	2.9%	5.5%	**ULOA$_{bd}$ (N):**	42	**Group x Day**	2.736	0.112
	3-1 =	6.1%	5.3%	**LLOA$_{bd}$ (N):**	-99	**3-1 =**	14.5%	3.4%	**LLOA$_{bd}$ (N):**	-109			
	CV$_{ws}$ =	5.4%		**CV$_{bd}$ =**	7.5%	**CV$_{ws}$ =**	8.7%		**CV$_{bd}$ =**	6.2%			
	ICC$_{ws}$ =	0.8		**ICC$_{bd}$ =**	0.77	**ICC$_{ws}$ =**	0.76		**ICC$_{bd}$ =**	0.78			
W$_{pk}$	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	51	**CV (%)**	**D1**	**D2**	**Mean diff$_{bd}$ (N):**	15	**Group**	0.014	0.906
	2-1 =	4.7%	3.3%	**Mean diff$_{bd}$ (%):**	5.2%	**2-1 =**	3.8%	3.3%	**Mean diff$_{bd}$ (%):**	1.6%	**Day**	7.124	0.014*
	3-2 =	2.5%	2.9%	**ULOA$_{bd}$ (N):**	65	**3-2 =**	6.3%	4.3%	**ULOA$_{bd}$ (N):**	55	**Group x Day**	2.071	0.164
	3-1 =	4.6%	4.2%	**LLOA$_{bd}$ (N):**	-77	**3-1 =**	5.8%	2.8%	**LLOA$_{bd}$ (N):**	-93			
	CV$_{ws}$ =	3.9%		**CV$_{bd}$ =**	4.8%	**CV$_{ws}$ =**	4.6%		**CV$_{bd}$ =**	4%	**Post hoc:**		
	ICC$_{ws}$ =	0.76		**ICC$_{bd}$ =**	0.74	**ICC$_{ws}$ =**	0.78		**ICC$_{bd}$ =**	0.81	D2-D1		0.014*

D1 = day 1, D2 = day 2, MVIC = peak force for maximum voluntary isometric contraction, IKD60 = peak force at $60^{o}s^{-1}$, IKD120 = peak force at $120^{o}s^{-1}$, IKD180 = peak force at $180^{o}s^{-1}$, W_{pk} = peak power in 6 s sprint cycle test, REC ≥ 48 h recovery, CONSEC = consecutive days, CV = coefficient of variation, CV_{ws} =within-day CV, CV_{bd} = between-day CV, ICC = intra-class correlation coefficient, ICC_{ws} = within-day ICC, ICC_{bd} = between-day ICC, Mean $diff_{bd}$ = between-day mean difference, ULOA = Upper 95% limit of agreement, LLOA = Lower 95% limit of agreement, * = $p \leq 0.05$. Post hoc comparisons for 3-way ANOVA: MVC D2 Vs D1: $p = 0.015$**;** IKD60 REC D2 Vs D1: $p = 0.370$, CONSEC D2 Vs D1: $p = 0.045$**;** IKD120 REC D2 Vs D1: $p = 0.089$; CONSEC D2 Vs D1: $p = 0.007$**;** W_{pk} D2 Vs D1: $p = 0.002$

Table 2. Measured interface pressures, within session and between-day reliability coefficients

		REC			CONSEC			
		Within-session	Between-day			Within-session	Between-day	
Ankle (B point)	P_{ave} (mmHg)	15 ± 6	Mean diff (mmHg)	-1	P_{ave} (mmHg)	15 ± 7	Mean diff (mmHg)	0
	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	3	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	3
	CV_{ws}%	6.7	CV_{bd}%	17	CV_{ws}%	5.8	CV_{bd}%	17
	ICC_{ws}	0.79	ICC_{bd}	0.53	ICC_{ws}	0.9	ICC_{bd}	0.75
			ULOA	7			ULOA	8
			LLOA	-9			LLOA	-9
B1	P_{ave} (mmHg)	21 ± 9	Mean diff (mmHg)	0	P_{ave} (mmHg)	22 ± 11	Mean diff (mmHg)	1
	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	3	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	3
	CV_{ws}%	5.6	CV_{bd}%	12.9	CV_{ws}%	7.2	CV_{bd}%	13.7
	ICC_{ws}	0.83	ICC_{bd}	0.63	ICC_{ws}	0.94	ICC_{bd}	0.75
			ULOA	9			ULOA	10
			LLOA	-8			LLOA	-9
Calf (C point)	P_{ave} (mmHg)	18 ± 7	Mean diff (mmHg)	0	P_{ave} (mmHg)	19 ± 10	Mean diff (mmHg)	1
	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	1	CV_{ws} (mmHg)	2	CV_{bd} (mmHg)	3
	CV_{ws}%	5.7	CV_{bd}%	8.1	CV_{ws}%	8.4	CV_{bd}%	15.4
	ICC_{ws}	0.81	ICC_{bd}	0.89	ICC_{ws}	0.92	ICC_{bd}	0.8
			ULOA	4			ULOA	10
			LLOA	-4			LLOA	-8
Thigh (F point)	P_{ave} (mmHg)	12 ± 5	Mean diff (mmHg)	-1	P_{ave} (mmHg)	13 ± 6	Mean diff (mmHg)	-1
	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	1	CV_{ws} (mmHg)	1	CV_{bd} (mmHg)	1
	CV_{ws}%	4.8	CV_{bd}%	9.9	CV_{ws}%	3.6	CV_{bd}%	6.8
	ICC_{ws}	0.82	ICC_{bd}	0.39	ICC_{ws}	0.86	ICC_{bd}	0.63
			ULOA	4			ULOA	3
			LLOA	-3			LLOA	-4

REC ≥ 48 h recovery, CONSEC = consecutive days, CV = coefficient of variation, CVws=within-session CV, Pave = mean pressure over two days, CVbd = between-day CV, ICC = intra-class correlation coefficient, ICCws = within-session ICC, ICCbd = between-day ICC, Mean diffbd = between-day mean difference, B = narrowest point of the ankle, C = greatest calf circumference, B1 = point equidistant between B and C, F = point equidistant between the inguinal fold and patella, ULOA = Upper 95% limit of agreement, LLOA = Lower 95% limit of agreement.

Discussion

This is the first study to directly compare the between-day variation of isometric and isokinetic performance tests, between participants tested on consecutive and non-consecutive days. Completing a battery of maximal isometric and isokinetic muscular strength assessments (~ 13 repetitions in total) significantly impaired next-day performance, with peak force declining in CONSEC for MVIC, IKD60 and IKD120 by 10%, 9.0% and 5.3% respectively. These effects were mitigated by providing ≥ 48 h recovery. The potential for dynamometry to impair next-day performance should therefore be considered when interpreting the results from studies on muscular recovery. Furthermore, considerable variability in interface pressure measurements was observed. Researchers would therefore be advised to report reliability coefficients alongside pressure readings to quantify potential variation.

The magnitude of performance impairment observed in the present study appears similar to that attributed to EIMD induced by isometric exercise in untrained participants [9-11]. Of note, we observed next-day performance deficits only at isometric or slower isokinetic speeds, with no decline apparent at $180^{o}s^{-1}$, or for W_{pk} (Table 1). This greater decline in absolute force vs velocity further supports the notion that deterioration was due to EIMD [5, 32]. Furthermore, as the magnitude of EIMD is proportional to exercise volume [6], our findings may help explain the inconsistent levels of EIMD reported in previous studies. For example, whilst Tseng at al. [9] previously reported an 18% reduction in isokinetic ($30^{o}s^{-1}$) performance, 24 h after 60 MVICs (3 s) in 26 non-resistance trained men (21 ± 1 y), Hibbert et al. [11] more recently observed only a 5.3% decline in IKD60 between days. This protocol featured a reduced exercise volume and greater recovery times than that of Tseng (1.8 ± 0.7 days), with three sessions of 3 x MVIC (5 s) and 3 x IKD60 being held over one week in 25 healthy participants (21 ± 3 y, 13 males, 12 females). Importantly, however, the authors did not isolate the effects of consecutive daily testing. Whilst participants visited the laboratory on non-consecutive days “where possible”, average recovery times demonstrate that several participants tested on consecutive days. The 5-10% between-day performance impairments observed in CONSEC in the present study therefore appear typical of EIMD responses in non-resistance trained participants, considering the moderate exercise volume (~ 13 x MVIC) and consecutive daily testing schedule employed.

The magnitude of performance deteriorations observed throughout consecutive daily testing should be considered when interpreting studies on recovery interventions. For example, while improvements of ≥ 3% are commonly regarded as meaningful [33], benefits of this magnitude may be masked by the additional strength losses induced by testing in non-resistance trained participants, which reached 10% in the current trial. Future studies should consider the effect of performance tests when estimating worthwhile effect and sample size, particularly in relation to participant training status and the total number of tests employed.

Another important finding from the present study is the lack of learning effects over two days of isometric and isokinetic testing. Similar findings have been reported elsewhere, with force dynamometry often proving resistant to familiarization in active populations [11, 34]. Between-day reliability coefficients for isokinetic (CV ranging from 3.5 – 9.4% across both groups) and isometric tests (5.7 - 6%) were also similar to those reported previously in non-resistance trained males [9] (CV = 5.3%) and from a recent study on a mixed-sex, recreationally active sample [11] (SEM = 8.8 – 9.5%), with neither study using a maximal prior familiarization session. However, it should be noted that these reliability values are specific to the population and protocol assessed. The warm-up used involved eccentric contractions, while both our protocol and that of Hibbert et al. [11] included submaximal efforts prior to each maximal test. Accordingly, we would recommend the use of a standardized warm-up, adhering to RAMP (raise, activate, mobilize, potentiate) guidelines [35]. The rapid familiarization observed in the present trial may also have been facilitated by participant positioning, with participants oriented in a reclined position, and strapping used to isolate the quadriceps. Difficulties in standardizing participant positioning may prevent the isolation of specific muscle groups, reducing reliability and increasing the number of visits required for adequate familiarization [36, 37]. The current procedures, including a comprehensive warm up and standardized participant positioning, were resistant to familiarization in non-resistance trained males.

In contrast to strength measures, peak cycling power was greater on D2 and improved between repetitions similarly on both days (Table 1). Although efforts were repeated until performance plateaued, this finding raises the possibility that familiarization may have been incomplete. Similar findings were reported by Mendez-Villanueva and colleagues (2007), who demonstrated that performance improved in moderately trained males between the first and second days, when peak power was assessed over four testing sessions. Whilst the authors reported no further improvements, we are unable to confirm whether two sessions provided sufficient familiarization in the current study, as performance was not assessed on a third day.

The present findings also contribute to current knowledge on CG pressure monitoring. Although there is much controversy over the accuracy of pneumatic pressure monitors such as the Picopress [38], our calibration with a mercury column (demonstrating a highly significant correlation) suggests the sensor was highly accurate from 0 – 30 mmHg. Despite this level of accuracy however, discrete interface pressures may not necessarily reflect average pressures around the limb circumference [19, 39]. Furthermore, considerable variability was observed between participants and between days. Between-participant variation ranged from 5 mmHg at the thigh (44%) to 11 mmHg at the B1 point (50%), despite the use of the Picopress to guide initial garment fitting. Additionally, reliability expressed as typical error varied between 1 – 2 mmHg over all sights within sessions (3.6 – 8.4%), and between 1 – 3 mmHg between days (6.8 – 17%), confirming that removing and donning CG leads to variation in pressure [21]. Indeed, between-day differences of 2 – 4 mmHg at the thigh were observed in REC, resulting in ICC = 0.39 at this point. If optimum pressures are indeed required for haemodynamic effects [29] and enhanced exercise recovery [16, 20], then such variability could dramatically reduce the likelihood that CG will be effective. However, the large pressure ranges given by the British Drug Tariff to classify compression [40], as well as anthropometric variation between individuals [20], makes such variation hard to avoid when using standard sized garments. Future studies assessing the use of CG should measure the pressures exerted by CG throughout recovery to monitor changes between days.

It must be acknowledged that these reliability data are specific to the population studied, and specific testing procedures employed. Other limitations of the current study include the relatively small sample size, and variation in recovery times in REC. Furthermore, the reliability of garment measurements will also be specific to the stockings used in this study, while neither the age of each garment, nor the number of prior washes were controlled.

Conclusions

Isometric and isokinetic testing were resistant to familiarization in non-resistance trained males, while reliability was similar to previously reported values. However, peak performance declined when tests were repeated on consecutive days, which may influence researchers' abilities to quantify recovery. The 6 s sprint cycle test required at least one familiarization session. In-vivo CG pressure measurements are affected by removing and reapplying the garments, which may lead to meaningful variation. Further research is needed to quantify the deterioration of interface pressures in relation to the reliability of these measurements. Such data may help guide the selection of CG that provide consistent and adequate pressures throughout recovery.

Competing interests

The authors have no funding, nor conflicts of interest to report

Ethical approval for research on humans

Institutional ethics approval was obtained prior to data collection (Ref P93660)

Informed consent

Written consent was obtained from all participants. Participants were adults and able to provide informed consent

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