Reliability of the HUMAC360 to Measure Movement Velocity during Three Equal Segments of the Barbell Back Squat

Original Research

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Abstract

Introduction: Linear position transducers (LPT) are commonly used to assess movement velocity during full concentric movements, but fail to account for fluctuations in velocity throughout the movement. This investigation aimed to determine inter-set and inter-day reliability of the HUMAC360 LPT during three equal segments of the barbell back squat.
Methods: Seventeen participants with resistance exercise experience completed an informed consent and a one-repetition maximum (1RM) on their initial visit, with two additional visits consisting of two sets of three repetitions at 30-, 50-, 60- and 70% of 1RM with ≥ 48H between visits. The LPT was attached to the medial aspect of the barbell sleeve to assess velocity. Repetitions were segmented into thirds based on distance as the top, middle and bottom portion of the movement. Intraclass Correlation Coefficients (ICC), standard error of the measurement and paired samples t-tests were used to assess mean velocity (MV), peak velocity (PV) and duration reliability.
Results: When using the average of the three repetitions, good-to-excellent ($ICC_{2,1}$=0.708-0.993) inter-set and inter-day MV and PV ICCs were noted across all intensities and segments. The top and middle portion exhibited stronger reliability measures compared to the bottom. Movement velocity was not significantly different ($p>0.05$) at any exercise intensity, with the exception of MV at 60% during the top portion of the movement ($p=0.045$).
Conclusions: The HUMAC360 provides reliable measures of mean velocity and peak velocity during each segment of the barbel back squat.

Key Words: velocity-based training; resistance exercise; strength and conditioning

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Introduction

Velocity-based training (VBT) is a type of resistance exercise training that utilizes decreases in concentric movement velocity (CMV) (i.e., a reduction in velocity from the initial repetition of a set) as an indicator of acute muscular fatigue [1]. The objective of VBT is to perform each repetition with maximum velocity and monitor CMV on a repetition-by-repetition basis and terminate the set once CMV falls below a preset threshold[2]. This enables strength and conditioning personnel to monitor fatigue more accurately throughout training. When compared to more traditional resistance exercise modalities, recent evidence has suggested VBT may result in similar, if not greater muscular strength and athletic performance adaptations (i.e., vertical jump and sprint measures)[1–3]. Collectively, strength and conditioning personnel can utilize VBT as an effective resistance exercise modality for various athletic populations.

Currently, CMV is commonly measured with linear position transducers during resistance exercise training sessions [1–5]. Linear position transducers are devices that rest on the floor and connect to the barbell via a retractable cable which measures displacement with respect to time, and can be used to determine CMV [6]. Previous investigations have reported linear position transducers, as well as linear velocity transducers (i.e., devices similar to linear position transducers but measure velocity rather than displacement) such as the Tendo Unit (Tendo Sports; London; UK) to be a valid and reliable tool to measure CMV [7]. Additionally, a recent investigation reported the HUMAC360 Linear Position Transducer (LPT; Computer Sports Medicine, Inc., Stoughton, MA) to reliably measure CMV during the barbell back squat movement [8]. This enables strength and conditioning programs to not only monitor CMV in real time, but also accurately monitor changes in CMV across training with these devices.

At present, an issue with linear position transducers is a limited ability to segment movements into different phases. Previous investigations have segmented resistance exercise around a sticking region [the point at which the barbell reaches a minimum velocity following the first initial maximum velocity [9–11], and have reported failure of a repetition will occur during the sticking region [12]. The sticking region has been reported to occur around 0.10m from the start of the ascent phase during the barbell back squat [9,10], with a drastic increase in concentric movement velocity (CMV) following the sticking region [9,10]. Fluctuations in movement velocity are not accounted for when the average CMV across the entire ascent phase is used. Therefore, segmenting CMV into different phases may be a more appropriate measurement, rather than using the average CMV during the entire ascent phase. This would enable strength and conditioning personnel to monitor velocity during these more consequential segments of the barbell back squat and determine if strength improvements have occurred or monitor proximity to failure

To date, no studies have reported the reliability of a linear position transducer to measure CMV across different segments of the barbell back squat. The LPT raw data output provides practitioners with the ability to segment each repetition into different phases, which may enable researchers and strength and conditioning personnel to accurately monitor acute muscular fatigue and performance across training. Therefore, the primary purpose of this investigation was to determine inter-set and inter-day CMV reliability of the LPT during different segments of the barbell back squat. We hypothesized the linear position transducer would provide a reliable measure of CMV during all segments of the barbell back squat.

Methods

Experimental Approach to the Problem

A within-subjects design was used to determine the inter-set and inter-day reliability of the LPT during the concentric phase of barbell back squat during three equal segments (top (TOP), middle (MID) and bottom (BOT) third). The current data set is a subsequent analysis of data describing the validity and reliability of velocity measures during the full concentric movement [8]. Participants reported to the Exercise Performance and Recovery Laboratory on three separate occasions, with at least 48 hours between visits. During visit one, participants provided informed written consent to participate in the study before completing a medical and health history questionnaire, anthropometric assessments, and a one-repetition maximum (1RM) of the squat. Visits two and three consisted of a standardized warm-up, followed by two sets of three repetitions at 30-, 50-, 60-, and 70% 1RM. The LPT was attached to the medial aspect of the barbell sleeve with the retractable belt perpendicular to the ground, to record mean velocity (MV), peak velocity (PV) and the duration of each phase (D). This design enabled us to compare measures of concentric movement velocity between multiple resistance exercise intensities, sets, and days with the LPT.

Participants

Twenty recreationally active men and women with at least six months of prior resistance training experience volunteered to participate in this study. Sample size was estimated from an ICC power analysis calculator [13]. Utilizing a minimal acceptable ICC of 0.60, expected ICC of 0.90, a = 0.05, statistical power of 80%, and number of replicates per subject of k = 2, the estimated sample size was 14. Two individuals were removed from data analysis due to inconsistent exercise technique, and one individual who experienced an injury outside of data collection. Therefore, seventeen individuals (N = 12 males/5 females; 24 ± 4 years; 1.71 ± 0.07m; 80.8 ± 11.2kg; 1.40 ± 0.40 relative 1RM) were included for data analysis. Any individual who reported recent (i.e., within six months) or current injury were excluded from this study. All participants were informed of the study design, as well as the risks and benefits of participation prior to data collection. This study protocol (IRB #: 21-031) was in accordance and approved by the University's Institutional Review Board.

Protocol

Visit One: All experimental protocols were performed in a controlled laboratory environment under similar environmental conditions (i.e, temperature, humidity and barometric pressure). Participants were instructed to abstain from caffeine for 16 hours, alcohol for 24 hours and exercise for 24 hours prior to each visit. Height and body mass were assessed using a Healthometer 500KL specialty scale (McCook, IL). Following anthropometric testing, participants completed a standardized warm-up of cycling for five minutes at a self-selected pace on a stationary ergometer (Schwinn Airdyne, Vancouver, WA), followed by 10 bodyweight squats and 10 walking lunges. Participants were then assessed for maximal strength via a standardized 1RM protocol [14]. The 1RM assessment consisted of performing three warm-up sets using five to ten repetitions, three to five repetitions, and two to three repetitions based off an estimated 1RM in a squat stand (Rogue Fitness, Columbus, OH), with load increasing 10-20% for each warm-up set. Participants were allotted up to five attempts to determine their 1RM, which was considered to be the maximum amount of weight the participant could move through the full range of motion while maintaining proper technique.

Visits Two & Three: An identical experimental protocol was completed on visits two and three. Each participant performed the same standardized warm-up (i.e., five minutes of stationary cycling followed by 10 bodyweight squats and 10 walk lunges), followed by two sets of three repetitions at 30-, 50-, 60-, and 70% 1RM in an ascending fashion. Participants were instructed to perform the concentric phase of each repetition with maximal velocity, while performing the eccentric phase in a slow and controlled manner. Participants were provided with three to five minutes of rest between each set. The LPT was placed on the floor and attached to the medial aspect of the barbell sleeve to align with the vertical path of the barbell back squat.

Determination of Velocity: The LPT measured changes in barbell displacement at 100Hz and did not require calibration prior to use. Raw position data was exported into a customized Excel spreadsheet (Microsoft Corporation, Redmond, WA), that calculated the variables of interest. Each repetition and measurement were automatically determined and calculated via the spreadsheet once raw position data was imported. Velocity was determined by change in position at 100Hz before being filtered with a 0.10s rolling average. Repetitions were identified by a displacement exceeding 0.15m, while the onset of each repetition was defined as filtered velocity exceeding $0.05 m \cdot s^{-1}$.The TOP, MID and BOT segments were then determined by dividing each concentric phase of a repetition into equal thirds based on total displacement. Once segmented, the MV, PV and D were determined for each phase independently. Briefly, MV was defined as the average velocity across the entire repetition phase, while PV was the point with the highest velocity; D was how long each repetition segment took to complete. Measures of MV, PV and D were calculated from the average of the three repetitions across the set (AR) and from the repetition with the highest MV, which was defined as the best repetition (BR).

Statistical Analysis

Inter-set and inter-day MV, PV and D reliability was assessed using paired sample t-test and Intraclass Correlation Coefficients (ICC). $ICC_{2,k}$, $ICC_{2,1}$, standard error of the measurement (SEM) and minimal difference (MD) were analyzed in a custom-build Excel template from previously reported procedures [15], while paired sample t-tests were analyzed using SPSS software version 28.0 (SPSS, Chicago, IL). For inter-set reliability, MV, PV and D of the AR and the BR per set were compared to the corresponding values across set one and two. For inter-day reliability, the AR and the BR from the set with the highest MV were compared for MV, PV and D from visits two and three. ICCs were utilized at the 95% confidence interval using a two-way mixed-effects model and categorized as poor (<0.50), moderate (0.50-0.75), good (0.75-0.90) and excellent (>0.90) according to previously published standards [16]. Significance was set at $p \leq 0.05$.

Results

Inter-set: The AR data is displayed in Table 1, while BR data is displayed in Table 2. Measures of MV, PV, and D for AR data resulted in excellent ICCs across all intensities and segments, except for D at 50% during the MID portion of the back squat, which resulted in a moderate ICC. Reliability was decreased for BR data relative to AR, however, MV and PV measures demonstrated good-to-excellent ICCs across all intensities and segments for BR, besides for PV at 60% during the BOT portion of the back squat, which resulted in a moderate ICC. Measures of D resulted in good ICCs across all intensities and segments for BR, besides for 50% during the MID portion of the back squat, which resulted in a poor ICC.

Table 1. Displays inter-set reliability for mean velocity, peak velocity and duration during the TOP, MID and BOT portion of the back squat from the average of the three repetitions across the set.

		Mean Velocity (*m • s*$^{-1}$)				Peak Velocity (*m • s*$^{-1}$)				Duration (*s*)			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
TOP	**ICC$_{2,k}$**	**0.991**	**0.979**	**0.991**	**0.991**	**0.989**	**0.967**	**0.993**	**0.992**	**0.967**	**0.925**	**0.969**	**0.983**
	SEM$_{2,k}$	0.032	0.043	0.024	0.023	0.049	0.070	0.029	0.032	0.012	0.017	0.010	0.006
	p	0.750	0.846	*0.045**	0.614	0.309	0.452	0.147	1.000	0.361	1.000	0.269	0.361
	MD	0.09	0.13	0.05	0.07	0.14	0.20	0.07	0.10	0.03	0.05	0.03	0.02
Mean (SD)	**Set 1**	0.89 (0.24)	0.83 (0.19)	0.81 (0.19)	0.74 (0.18)	1.32 (0.33)	1.19 (0.24)	1.11 (0.24)	1.00 (0.25)	0.26 (0.05)	0.26 (0.04)	0.27 (0.03)	0.28 (0.04)
	Set 2	0.88 (0.23)	0.83 (0.22)	0.79 (0.18)	0.74 (0.18)	1.34 (0.33)	1.17 (0.30)	1.10 (0.24)	1.01 (0.25)	0.26 (0.04)	0.27 (0.05)	0.27 (0.04)	0.28 (0.04)
MID	**ICC$_{2,k}$**	**0.983**	**0.934**	**0.973**	**0.967**	**0.987**	**0.943**	**0.985**	**0.983**	**0.928**	0.681	**0.978**	**0.936**
	SEM$_{2,k}$	0.049	0.060	0.029	0.032	0.047	0.072	0.029	0.033	0.009	0.021	0.007	0.016
	p	0.259	0.423	0.461	0.798	0.279	0.299	0.234	0.799	0.238	0.173	0.805	0.766
	MD	0.12	0.16	0.08	0.09	0.13	0.19	0.08	0.09	0.02	0.05	0.02	0.05
Mean (SD)	**Set 1**	1.10 (0.25)	0.94 (0.14)	0.82 (0.12)	0.68 (0.12)	1.26 (0.30)	1.10 (0.18)	0.99 (0.17)	0.85 (0.17)	0.13 (0.02)	0.15 (0.02)	0.18 (0.03)	0.22 (0.04)
	Set 2	1.12 (0.25)	0.92 (0.19)	0.82 (0.13)	0.68 (0.14)	1.28 (0.29)	1.07 (0.24)	0.97 (0.18)	0.84 (0.18)	0.13 (0.02)	0.16 (0.03)	0.18 (0.04)	0.22 (0.05)
BOT	**ICC$_{2,k}$**	**0.978**	**0.971**	**0.968**	**0.985**	**0.976**	**0.938**	**0.947**	**0.965**	**0.947**	**0.940**	**0.932**	**0.969**
	SEM$_{2,k}$	0.023	0.018	0.020	0.014	0.040	0.044	0.031	0.026	0.018	0.017	0.024	0.020
	p	0.265	0.539	0.817	0.660	0.198	0.669	0.791	0.659	*0.048**	0.839	0.333	0.453
	MD	0.06	0.05	0.06	0.04	0.10	0.12	0.09	0.08	0.04	0.05	0.07	0.06
Mean (SD)	**Set 1**	0.50 (0.11)	0.46 (0.07)	0.43 (0.09)	0.39 (0.09)	0.90 (0.19)	0.77 (0.11)	0.69 (0.10)	0.58 (0.10)	0.26 (0.06)	0.28 (0.06)	0.32 (0.07)	0.37 (0.08)
	Set 2	0.51 (0.11)	0.46 (0.08)	0.44 (0.07)	0.39 (0.08)	0.92 (0.18)	0.76 (0.14)	0.69 (0.09)	0.58 (0.10)	0.24 (0.05)	0.29 (0.04)	0.31 (0.07)	0.38 (0.08)

TOP = top; MID = middle; BOT = bottom; ICC = Intraclass Correlation Coefficients; SEM = standard error of the measurement; MD = minimal difference; Excellent ICCs are bolded; *Denotes significance

Table 2. Displays inter-set reliability for mean velocity, peak velocity and duration during the TOP, MID and BOT portion of the back squat from the best of the three repetitions across the set.

		Mean Velocity (*m • s*$^{-1}$)				Peak Velocity (*m • s*$^{-1}$)				Duration (*s*)			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
TOP	**ICC$_{2,1}$**	**0.973**	**0.954**	**0.982**	**0.976**	**0.983**	**0.943**	**0.970**	**0.975**	0.893	0.859	0.896	**0.959**
	SEM$_{2,1}$	0.053	0.065	0.048	0.040	0.059	0.093	0.057	0.057	0.018	0.026	0.018	0.011
	p	0.507	0.901	0.130	0.457	0.430	0.669	0.060	0.776	0.187	0.716	0.431	0.072
	MD	0.11	0.13	0.06	0.08	0.12	0.19	0.10	0.12	0.02	0.05	0.04	0.02
Mean (SD)	**Set 1**	0.94 (0.23)	0.85 (0.20)	0.83 (0.18)	0.77 (0.18)	1.34 (0.31)	1.22 (0.26)	1.16 (0.24)	1.04 (0.25)	0.25 (0.03)	0.26 (0.05)	0.26 (0.03)	0.27 (0.04)
	Set 2	0.93 (0.23)	0.89 (0.23)	0.82 (0.18)	0.76 (0.18)	1.39 (0.32)	1.21 (0.29)	1.13 (0.23)	1.03 (0.27)	0.25 (0.03)	0.26 (0.05)	0.27 (0.04)	0.28 (0.04)
MID	**ICC$_{2,1}$**	**0.971**	**0.909**	0.892	**0.952**	**0.980**	**0.916**	**0.923**	**0.962**	0.804	0.481	0.819	0.889
	SEM$_{2,1}$	0.056	0.074	0.061	0.040	0.056	0.093	0.071	0.050	0.014	0.022	0.020	0.021
	p	0.665	0.506	0.162	0.656	0.516	0.517	0.114	0.404	0.855	0.127	0.557	0.826
	MD	0.11	0.15	0.12	0.08	0.11	0.18	0.13	0.10	0.03	0.05	0.04	0.04
Mean (SD)	**Set 1**	1.16 (0.22)	0.97 (0.16)	0.87 (0.12)	0.73 (0.12)	1.32 (0.24)	1.13 (0.20)	1.03 (0.17)	0.88 (0.17)	0.12 (0.03)	0.15 (0.02)	0.17 (0.03)	0.20 (0.04)
	Set 2	1.17 (0.24)	0.96 (0.19)	0.85 (0.14)	0.73 (0.13)	1.33 (0.29)	1.12 (0.25)	1.01 (0.18)	0.89 (0.19)	0.12 (0.02)	0.16 (0.03)	0.17 (0.04)	0.20 (0.05)
BOT	**ICC$_{2,1}$**	**0.955**	**0.941**	0.841	**0.942**	**0.950**	0.899	0.697	0.877	0.794	0.836	0.813	0.896
	SEM$_{2,1}$	0.031	0.026	0.042	0.029	0.054	0.058	0.072	0.047	0.029	0.027	0.033	0.022
	p	0.813	0.654	0.391	0.345	0.586	0.553	0.260	0.068	0.623	0.545	0.569	0.702
	MD	0.06	0.05	0.08	0.06	0.11	0.12	0.14	0.09	0.06	0.05	0.07	0.06
Mean (SD)	**Set 1**	0.54 (0.10)	0.47 (0.08)	0.46 (0.08)	0.41 (0.08)	0.95 (0.16)	0.79 (0.12)	0.72 (0.10)	0.61 (0.08)	0.23 (0.05)	0.27 (0.05)	0.30 (0.05)	0.34 (0.07)
	Set 2	0.53 (0.11)	0.47 (0.08)	0.45 (0.07)	0.42 (0.09)	0.94 (0.18)	0.78 (0.14)	0.70 (0.09)	0.63 (0.11)	0.23 (0.04)	0.28 (0.05)	0.31 (0.06)	0.34 (0.07)

TOP = top; MID = middle; BOT = bottom; ICC = Intraclass Correlation Coefficients; SEM = standard error of the measurement; MD = minimal difference; Excellent ICCs are bolded

<u>Inter-day:</u> The AR data is displayed in Table 3, while BR data is displayed in Table 4. Measures of MV and PV for AR resulted in good-to-excellent ICCs across all intensities and segments, besides for PV at 60- and 70% during the BOT portion of the back squat, which resulted in moderate ICCs. D resulted in good ICCs during the TOP segment for AR, but poor-to-moderate ICCs for the MID and BOT segment of the back squat. Reliability was decreased for BR data relative to AR, however, MV and PV measures demonstrated good-to-excellent ICCs across all intensities during TOP and MID for BR, while exhibiting moderate-to-good ICCs for the BOT portion of the back squat, with one exception in PV at 70% during the BOT portion which resulted in a poor ICC. Measures of D resulted in moderate-to-good ICCs at the TOP for BR, and poor-to-moderate ICCs at the BOT and MID portion of the back squat.

Table 3. Displays inter-day reliability for mean velocity, peak velocity and duration during the TOP, MID and BOT portion of the back squat from the average of the three repetitions across the set.

		Mean Velocity ($m \bullet s^{-1}$)				**Peak Velocity ($m \bullet s^{-1}$)**				**Duration (s)**			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
TOP	**$ICC_{2,k}$**	**0.945**	0.872	**0.913**	**0.935**	**0.948**	**0.912**	**0.904**	**0.909**	0.779	0.828	0.868	0.885
	$SEM_{2,k}$	0.083	0.091	0.069	0.057	0.116	0.100	0.098	0.094	0.031	0.022	0.017	0.018
	p	0.664	0.157	0.256	0.346	0.798	0.055	0.198	0.335	0.376	0.520	0.548	0.926
	MD	0.24	0.22	0.18	0.15	0.33	0.23	0.25	0.25	0.08	0.06	0.05	0.05
Mean (SD)	**Day 1**	0.90 (0.24)	0.84 (0.20)	0.81 (0.18)	0.75 (0.18)	1.35 (0.33)	1.21 (0.25)	1.12 (0.25)	1.02 (0.25)	0.26 (0.04)	0.26 (0.04)	0.27 (0.03)	0.28 (0.04)
	Day 2	0.91 (0.26)	0.89 (0.15)	0.83 (0.15)	0.77 (0.14)	1.36 (0.39)	1.27 (0.22)	1.16 (0.20)	1.05 (0.19)	0.27 (0.05)	0.27 (0.03)	0.27 (0.03)	0.28 (0.04)
MID	**$ICC_{2,k}$**	**0.960**	**0.942**	**0.900**	0.889	**0.953**	**0.950**	**0.917**	0.895	0.587	0.461	0.876	-0.080
	$SEM_{2,k}$	0.074	0.073	0.053	0.054	0.099	0.059	0.065	0.070	0.033	0.035	0.018	0.116
	p	0.742	0.868	0.559	0.329	0.972	0.250	0.919	0.844	0.111	0.070	0.156	*0.001**
	MD	0.21	0.14	0.14	0.14	0.29	0.16	0.18	0.19	0.07	0.07	0.04	0.19
Mean (SD)	**Day 1**	1.13 (0.25)	0.95 (0.15)	0.83 (0.13)	0.70 (0.12)	1.29 (0.30)	1.11 (0.19)	1.00 (0.18)	0.86 (0.17)	0.13 (0.02)	0.15 (0.02)	0.18 (0.03)	0.36 (0.08)
	Day 2	1.12 (0.28)	0.94 (0.15)	0.82 (0.11)	0.68 (0.11)	1.29 (0.35)	1.13 (0.18)	1.00 (0.14)	0.86 (0.13)	0.14 (0.04)	0.17 (0.04)	0.19 (0.04)	0.27 (0.05)
BOT	**$ICC_{2,k}$**	**0.956**	0.865	0.842	0.781	**0.963**	0.834	0.724	0.708	0.648	0.177	0.626	0.535
	$SEM_{2,k}$	0.033	0.038	0.041	0.046	0.054	0.053	0.068	0.068	0.053	0.074	0.061	0.106
	p	0.516	0.780	0.526	0.254	0.822	0.502	0.320	0.154	0.116	*0.028**	*0.045**	*0.047**
	MD	0.09	0.10	0.11	0.11	0.16	0.15	0.17	0.16	0.12	0.14	0.13	0.22
Mean (SD)	**Day 1**	0.51 (0.11)	0.47 (0.07)	0.44 (0.08)	0.40 (0.08)	0.92 (0.19)	0.78 (0.12)	0.70 (0.10)	0.59 (0.10)	0.24 (0.06)	0.28 (0.05)	0.31 (0.06)	0.36 (0.08)
	Day 2	0.52 (0.11)	0.46 (0.07)	0.44 (0.06)	0.38 (0.06)	0.92 (0.21)	0.72 (0.11)	0.68 (0.08)	0.56 (0.07)	0.29 (0.07)	0.32 (0.06)	0.34 (0.07)	0.30 (0.13)

TOP = top; MID = middle; BOT = bottom; ICC = Intraclass Correlation Coefficients; SEM = standard error of the measurement; MD = minimal difference; Excellent ICCs are bolded *Denotes significance

Discussion

To our knowledge, this is the first investigation to segment and analyze CMV into equal thirds during the barbell back squat. We hypothesized the LPT would provide reliable inter-set and inter-day measures of CMV during all segments of the barbell back squat. The present data suggests the LPT can provide reliable inter-set and inter-day measurements for MV and PV across all segments (i.e., TOP, MID, BOT) and intensities (i.e., 30-, 50-, 60- and 70% 1RM). Measurement based on the average of three repetitions (AR) provided the most reliable inter-set and inter-day measures of MV, PV and D, when compared to the BR, therefore strength and conditioning personnel should use AR over BR to monitor changes more accurately in CMV during and across training. However, based on the present data, the reliability for inter-day D should be utilized with caution during the MID and BOT portion of the movement.

Previously, our lab assessed the validity and reliability of the LPT during the full squat movement at 30-, 50-, 60- and 70% 1RM [8]. These data suggest the LPT can reliability measure inter-set and inter-session measures of CMV at 30-, 50- and 60% 1RM [8]. Similar to the data obtained in this investigation, AR provided more reliable measures of CMV as compared to BR during the full squat movement [8]. Additionally, similar measures of ICCs were observed at 30-, 50- and 60% 1RM, however, segmenting the movement into thirds tended to provide better measures of ICCs at 70%

Table 4. Displays inter-day reliability for mean velocity, peak velocity and duration during the TOP, MID and BOT portion of the back squat from the best of the three repetitions across the set.

		Mean Velocity (*m • s-1*)				Peak Velocity (*m • s-1*)				Duration (*s*)			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
TOP	**$ICC_{2,1}$**	0.896	0.775	0.847	0.860	0.886	0.830	0.861	0.822	0.593	0.657	0.771	0.772
	$SEM_{2,1}$	0.109	0.123	0.088	0.082	0.168	0.143	0.116	0.132	0.028	0.021	0.021	0.022
	p	0.802	0.104	0.330	0.564	0.583	0.061	0.405	0.418	0.058	0.603	0.660	1.000
	MD	0.22	0.23	0.17	0.16	0.34	0.26	0.23	0.26	0.06	0.06	0.04	0.05
Mean (SD)	**Day 1**	0.95 (0.23)	0.89 (0.21)	0.83 (0.17)	0.78 (0.18)	1.40 (0.32)	1.23 (0.26)	1.12 (0.24)	1.05 (0.25)	0.25 (0.030)	0.26 (0.04)	0.26 (0.03)	0.27 (0.04)
	Day 2	0.96 (0.25)	0.92 (0.15)	0.85 (0.15)	0.79 (0.13)	1.42 (0.38)	1.30 (0.22)	1.18 (0.19)	1.08 (0.19)	0.27 (0.04)	0.26 (0.03)	0.27 (0.03)	0.27 (0.03)
MID	**$ICC_{2,1}$**	**0.912**	0.877	0.799	0.819	**0.907**	0.886	0.840	0.814	0.582	0.445	0.607	0.030
	$SEM_{2,1}$	0.107	0.077	0.078	0.071	0.136	0.094	0.091	0.098	0.028	0.030	0.032	0.097
	p	0.963	1.000	0.489	0.251	0.648	0.267	1.000	0.905	*0.050**	*0.022**	0.177	*0.000**
	MD	0.22	0.16	0.16	0.14	0.27	0.18	0.18	0.20	0.05	0.06	0.06	0.14
Mean (SD)	**Day 1**	1.18 (0.24)	0.98 (0.17)	0.88 (0.13)	0.74 (0.12)	1.34 (0.29)	1.14 (0.21)	1.03 (0.17)	0.90 (0.18)	0.12 (0.02)	0.14 (0.02)	0.17 (0.03)	0.34 (0.06)
	Day 2	1.18 (0.27)	0.99 (0.14)	0.87 (0.11)	0.72 (0.11)	1.35 (0.34)	1.17 (0.18)	1.03 (0.15)	0.90 (0.14)	0.14 (0.04)	0.16 (0.04)	0.18 (0.04)	0.25 (0.05)
BOT	**$ICC_{2,1}$**	0.872	0.700	0.788	0.524	**0.905**	0.690	0.566	0.474	0.468	-0.010	0.561	0.345
	$SEM_{2,1}$	0.055	0.061	0.048	0.053	0.081	0.094	0.071	0.086	0.058	0.078	0.061	0.108
	p	0.479	0.751	0.764	0.123	1.000	0.816	0.691	0.157	*0.046**	*0.032**	0.145	*0.034**
	MD	0.11	0.12	0.10	0.12	0.16	0.19	0.16	0.16	0.10	0.14	0.12	0.19
Mean (SD)	**Day 1**	0.54 (0.11)	0.48 (0.08)	0.45 (0.08)	0.42 (0.07)	0.95 (0.18)	0.80 (0.13)	0.72 (0.10)	0.63 (0.09)	0.23 (0.04)	0.27 (0.05)	0.23 (0.05)	0.34 (0.06)
	Day 2	0.55 (0.11)	0.47 (0.08)	0.46 (0.07)	0.40 (0.06)	0.95 (0.20)	0.70 (0.11)	0.71 (0.08)	0.60 (0.08)	0.26 (0.06)	0.31 (0.06)	0.32 (0.07)	0.28 (0.11)

TOP = top; MID = middle; BOT = bottom; ICC = Intraclass Correlation Coefficients; SEM = standard error of the measurement; MD = minimal difference; Excellent ICCs are bolded *Denotes significance

1RM, when compared to the full movement. During the full movement AR inter-set and inter-session ICCs decreased to 0.548 and 0.448 respectively, at 70% 1RM [8]. While segmenting the movement into thirds also resulted in reduced inter-day ICC measures during the MID and BOT portion of the movement at 70% 1RM, the reductions observed in this investigation were rather small and classified as good (i.e., 0.889 for MID and 0.781 for BOT). Additionally, segmenting the movement into thirds tended to provide better SEMs, as compared to the full movement. During the full movement, AR inter-set and inter-session CMV SEMs ranged from 0.025-0.253 and 0.080-0.198 respectively, across all intensities [8], while segmenting the movement into thirds resulted in inter-set SEM measures of 0.014-0.060 and inter-day SEM measures of 0.033-0.091. Altogether, this suggests the LPT may provide more reliable measures of CMV when segmenting the movement into thirds, as compared to the full movement.

Previous investigations utilizing linear position and velocity transducers to determine inter-set or inter-day reliability have reported relatively similar ICCs [7,17,18] and less variable SEMs to the present data [18]. GymAware PowerTool has been reported to provide moderate-to-good inter-set displacement reliability during the full range of motion for the barbell back squat at intensities ≥ 70% 1RM with elite rugby players [17]. Barbell back squat inter-day CMV reliability for the Tendo Weightlifting Analyzer has been reported to be excellent with trained weightlifters [7], while good CMV reliability has been reported for the GymAware PowerTool with elite rugby players [18]. The present findings agree with these previously reported data, demonstrating excellent inter-set and moderate-to-excellent inter-day ICCs for MV and PV when using the AR. Absolute reliability, as reported via SEM, suggested varied inter-set (Table 1) and inter-day reliability (Table 3) during the barbell back squat at all intensities and segments. Inter-set tended to provide better absolute reliability measures as compared to inter-day (Tables 1 & 3). These data are more variable as compared to Orange et al. (2020), which reported good absolute inter-day reliability (i.e., 0.03-0.05 MV SEM & 0.06-0.09 PV SEM) for the barbell back squat. When compared to the present data, the LPT provided a wider range of SEM measures of MV (Table 3; 0.033-0.091), and PV (Table 3; 0.053-0.116). More varied SEMS compared to the aforementioned investigation may have resulted from a smaller sample size of the present study. Unlike these previous investigations, however, an innovative feature of our analysis is the segmentation of the full movement into thirds, which may provide more sensitive measures for strength and conditioning personnel to monitor muscle fatigue, as well as strength/power improvements across training.

One of the current objectives of VBT is to detect changes (i.e., decreases) in CMV, and to use these changes as an indicator of acute muscular fatigue [1]. However, since failure of a movement will most commonly occur around the sticking region (i.e., first 0.10m of the movement) [9,10], monitoring CMV may be most important during the BOT segment of the movement. During the BOT segment, the LPT provided excellent inter-set ICCs for MV and PV, good-to-excellent inter-day ICCs for MV and moderate-to-excellent inter-day ICCs for PV when using the AR. These data suggest the LPT is a viable device to detect changes in CMV during the BOT segment of the back squat, which is likely the most critical region to detect changes in velocity around the sticking point (i.e., region most likely to fail a lift), during and across training sessions.

Interestingly a prior investigation has reported no alterations in CMV following resistance exercise that induced muscle damage, as measured through increased concentrations of creatine kinase [19]. This lack of change in CMV may have occurred due to analyzing the full concentric movement, which fails to account for the known fluctuations in CMV that occur during the ascent phase of the movement [9,10]. Therefore, utilizing our approach of segmenting movement velocities into thirds may offer a more appropriate method to monitor muscle damage, as this provides more sensitive measures of CMV when compared to analyzing the full concentric movement.

There are a few limitations that should be addressed regarding the present investigation. Despite instructing participants to abstain from caffeine, alcohol and exercise prior to participating, these were only confirmed by self-report, and therefore may have not been followed by all participants. Participants not adhering to these guidelines may have reported to the laboratory either more fatigued or stimulated from visit two to three, thus resulting in decreased reliability from excellent inter-set ICCs to moderate-to-excellent inter-day ICCs for MV and PV across all segments and intensities when using the AR. This was also observed with the wider range of SEM measurements from inter-day (Table 3), as compared to inter-set (Table 1). Additionally, since the participants were college students, they did not always report to the lab at the same time of day from visit two to three to account for their schedules. This may have influenced performance measures such as movement velocity, as time of day has been reported to influence movement velocity during the bench press [20]. A limitation within the LPT is with the lack of calibration prior to use. Overtime, this may result in inconsistent measurements that can impact the data. However, we did follow the manufacturer guidelines throughout the protocol to prevent errors. Future investigations aiming to investigate reliability of the segmented thirds of the squat should utilize greater control mechanisms to determine if these variables influence the inter-day reliability. Additionally, future investigations should determine if velocity-loss is more prevalent during a specific phase of the movement (i.e., TOP, MID, BOT), and if this reduction in velocity is washed out while monitoring CMV during the full range of motion. This may provide further evidence for the need to segment movements into various phases when performing VBT."

Given that muscle damage has been previously reported to not influence CMV during the full concentric movement [19], future investigations aiming to use CMV as a tool to detect muscle damage should investigate if muscle damage influences CMV during the BOT segment, as this is the most critical region to detect failure of a lift. This will provide additional information into the impact muscle damage has on performance measures, and can be utilized as a tool to assess for muscle damage. Furthermore, future investigations should examine the impact chronic training bouts exert on neuromuscular fatigue and how this influences CMV during the BOT segment. Should chronic fatigue impact CMV during the BOT segment, analyzing this portion of the movement may be a useful assessment protocol to determine ones preparedness for training and competition. This will enable strength and conditioning personnel to perform back squats at various intensities and monitor CMV during the BOT segment to monitor the change in CMV from day to day and determine if an athlete is fully recovered from chronic training bouts.

Conclusions

Collectively, the results of this investigation support the original hypothesis and indicate the LPT can be used to reliably measure MV, PV, and D during the TOP, MID, and BOT segment of the barbell back squat across multiple sets and days; however, inter-day D should be used with caution during the MID and BOT segment. Segmenting the movement into thirds will permit strength and conditioning personnel to monitor these more sensitive changes in CMV, rather than utilizing the average CMV across the entire ascent phase. This will also allow researchers to use the LPT to investigate where acute muscular fatigue and muscle damage most influences CMV (i.e., during the TOP, MID or BOT segment), which will enable strength coaches to better develop VBT protocols. By observing reductions in CMV during various segments of the movement that may not occur during the full concentric movement, strength and conditioning personnel may help indicate acute muscular fatigue sooner and prevent injuries across training.

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