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Original Research

Reliability of a Linear Position Transducer During the Bench Press Across Three Segments

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Abstract

International Journal of Exercise Science 18(2): 622-635, 2025. https://doi.org/10.70252/OQIM2082 The purpose of this investigation was to determine inter-set and inter-session reliability of the HUMAC360 measures for duration (DUR), peak velocity (PV) and mean velocity (MV) across three segments of the bench press. Seventeen recreationally active adults participated in this investigation. During visit one, participants completed a bench press one-repetition maximum (1RM). Visits two and three consisted of two sets of three repetitions at 30%-, 50%-, 60%-, and 70 %-1RM. Segments were defined by dividing total displacement into equal thirds at the bottom (BOT), middle (MID) and top (TOP). Intraclass correlation coefficients (ICC) and standard error of measurement (SEM) were used to assess reliability while paired samples t-tests were used to identify differences between sets or sessions with significance set at $p \leq 0.05$. Excellent ICCs were present for PV and MV at most intensities in each segment between sets, while ICCs for DUR varied. MV and PV displayed excellent ICCs at lower intensities across segments between sessions, with decreases at higher intensities, while variable inter- session reliability for DUR was present across intensities and segments. The HUMAC360 reliably measured MV and PV during each segment across sets, though caution is warranted for DUR.

Keywords: Velocity-based training, resistance exercise, strength and conditioning

Introduction

Velocity-based training (VBT) is a method of auto-regulation that utilizes changes in velocity to provide a sensitive relative intensity for exercise prescription during resistance exercise sessions[1] and has been adopted by coaches due to its ability to afford insight regarding muscular fatigue and effort during resistance exercise.[2] While it is evident that VBT is an effective method to observe fatigue and effort, it is also necessary that the instruments implemented during VBT be a reliable instrument for measuring changes in barbell kinematics. One common and accessible method of implementing VBT is through the use of a linear position transducer (LPT), a device which measures displacement of a tethered cable commonly attached to a barbell, and can then be used to determine velocity as positions change with respect to time.[3] Common LPTs utilized for VBT include the Tendo Sport Weightlifting Analyzer (TENDO)(Tendo Sport; London; UK), and GymAware's Power Tool (GymAware; Mitchell, AU), which have both been extensively reviewed and displayed moderate to good interclass correlation (ICC) for mean and peak velocity between days across various exercises such as the bench press.[1,2,4]

To date, LPTs have been used to monitor velocity over the full range of motion (ROM) of the exercise,[1,2,5,6] however, prior reports have observed considerable position-dependent fluctuations in velocities over the course of the full ROM during the concentric phase of free weight exercises (i.e., the sticking region).[7,8] Under high intensities, the sticking region is presented by a minimal to near zero barbell velocity followed by a drastic increase in velocity over the remainder of the repetition.[9] These fluctuations in velocities around the sticking region are therefore lost when velocity is measured simply by peak or mean outcomes over the full ROM. Assessing velocity at a more granular level (i.e., segmental thirds of the ROM) may improve the ability to monitor position-dependent fluctuations in velocities influenced by the sticking region and provide greater insight to changes occurring at more consequential phases. Moreover, such observations may afford coaches and practitioners the opportunity to effectively monitor training fatigue, effort and improvements in muscular strength.

Many devices utilized for VBT do not support segmentation of the concentric phase, however the HUMAC360 LPT (Computer Sports Medicine, Inc., Stoughton, MA) affords the opportunity for raw data exportation, thereby allowing for possible segmental application and observations. The HUMAC360 LPT has previously been identified as a reliable measure of velocity, displacement and movement duration over the full concentric phase of the bench press, with impaired inter-day reliability noted at intensities exceeding 60% 1RM.[10] Therefore, the purpose of this investigation was to evaluate the inter-set and inter-session reliability of the HUMAC360 measurements of peak and mean velocity, as well as movement duration, across three equal segments of the concentric phase of bench press exercise. We hypothesized that the HUMAC360 LPT would provide reliable results for all measures for each segmental third of the concentric phase of the barbell bench press.

Methods

Participants

Twenty recreationally active men and women, between the ages of 18-30 years with at least six months of previous resistance training experience were recruited for this investigation. Sample size was derived by a sample size calculator for reliability investigations.[11] Based on prior findings of Pinzone et al[10], a minimum acceptable ICC of 0.6, an expected ICC of 0.9, a power of 80%, significance level (α) set at 0.05 and two replicates per participant (k = 2) provided a required a sample size of 14 individuals. Of the 20 recruited, two were excluded due to failure to execute proper exercise technique, while one was excluded due to sustaining an injury outside of this investigation. Therefore, a total of 17 participants completed the study (Age:24 ± 4 years, Height:1.71 ± 0.07m, Body Mass:80.8 ± 11.2kg). Participants were free of prescription medication, performance enhancing drugs, as well as free of musculoskeletal injuries, cardiovascular and/or metabolic disease, as assessed by a medical history questionnaire. Each participant completed and provided a written informed consent prior to completing any testing. All procedures were carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science* [12] and were approved by the University's Institutional Review Board prior to participant recruitment (IRB#: 21-031).

Protocol

A within-subjects design was used to determine inter-set and inter-session reliability of the HUMAC360 during three phases of the bench press exercise: bottom (BOT), middle (MID) and top (TOP) thirds of the concentric phase. Participants arrived at the Exercise Performance and Recovery Laboratory on three separate occasions with at least 48 hours between visits. During the initial visit, participants provided written informed consent before completing a health history questionnaire, anthropometric measurements, and a one repetition maximum (1RM) assessment for the barbell bench press. Visit two and three consisted of completing a standardized warmup followed by performing the bench press protocol, which consisted of two sets of three repetitions at 30-, 50-, 60-, and 70 % of each participant's previously determined 1RM and three minutes of rest between sets. An overview of the study design is depicted in Figure 1.

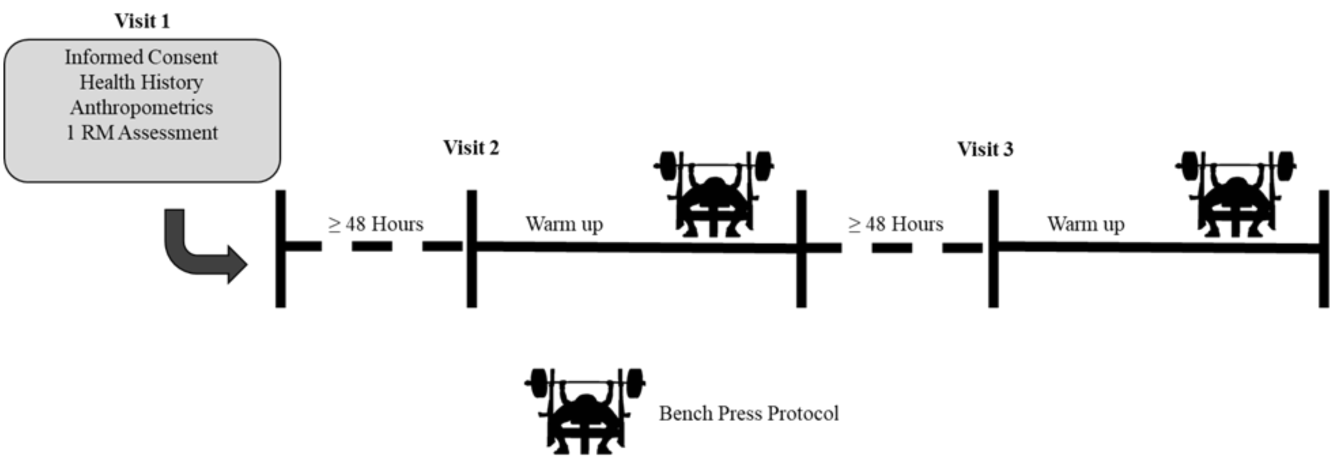

Figure 1. Study Design. Visit one consisted of preliminary testing while visit two and three, which were at least 48 hours later, consisted of completion of a bench press protocol comprised of two sets by three repetitions at ascending intensities (30-,50-60-70%) of individual's predetermined one-repetition max with three minutes of rest between sets. 1 RM= One repetition maximum, Hrs= Hours.

During the initial visit, participants completed an informed consent and health history questionnaire followed by anthropometric assessments for height and weight using a stadiometer and clinical scale (Healthometer, McCook, IL). As this was part of a larger investigation, participants then performed a 1RM assessment for the barbell back squat, using similar procedures.[13] Next, participants were provided a standardized warmup consisting of five-minute cycling on a stationary ergometer (Schwinn Airdyne, Vancouver, WA) followed by 10 body weight pushups prior to completing a 1RM assessment for the bench press performed within a power rack (Rouge Fitness, Columbus, OH) using a standardized protocol.[13] The 1RM assessment consisted of warmup sets using five to ten repetitions at 65% of perceived 1RM, three to five repetitions at 75% and two to three repetitions at 85% of perceived 1RM prior to increasing loads by 2.5-20% during each single repetition attempts. Participants were allotted up to five attempts to determine their 1RM, which was defined as the maximum amount of weight that could be moved safely and with appropriate form though a full ROM. Three minutes of rest were provided prior to each warmup set and working sets to determine the 1RM.

At least 48 hours from the initial visit, participants arrived at the laboratory for visits two and three, with at least 48 hours between study visits. Participants were instructed to abstain from caffeine for at least 16 hours, as well as avoid participating in strenuous exercise or consuming alcohol for at least 24 hours prior to the experimental trials. Initially, participants completed a standardized warm up and began the bench press protocol consisting of two sets of three repetitions at 30-, 50-, 60-, and 70% 1RM, with three minutes of rest between sets. Placement of the LPT was standardized per session and per participant. Specifically, the LPT was attached to the barbell on the medial side of the barbell sleeve, with the retractable belt positioned perpendicular to the ground, and in line with the movement of the exercise to record mean velocity (MV), peak velocity (PV), and movement duration (DUR) during each repetition. If requested, participants were provided a liftoff to initiate the starting position of the bench press. Participants were then instructed to perform the eccentric phase in a slow and controlled manner followed by the concentric phase being completed as explosively as possible for each repetition. At the end of the three repetitions, participants were assisted with racking the bar and were allotted three minutes of rest before beginning subsequent sets.

The HUMAC360 LPT measured barbell displacement at a frequency of 100Hz, with the raw position data then exported and analyzed in a customized Excel spreadsheet (Microsoft, Redmond, WA). Velocity was calculated by dividing the change in distance over the change in time before filtering with a 0.10s rolling average. The presence of a repetition was identified by a displacement of 0.10m, while the repetition onset was defined by a filtered velocity exceeding $0.05 m \cdot s^{-1}$. Segments of the movement were defined by dividing the total displacement into three equal thirds at the BOT, MID and TOP. The MV was defined as the mean velocity across the full segment, while PV was defined as the point with the greatest velocity during each segment, with DUR defined as the duration of each segment. Each variable was determined from the average of all three repetitions (AR) within a set and from the fastest repetition velocity (FRV), which was defined as the highest MV for the full movement.

Statistical Analysis

Inter-set and session reliability was determined using paired samples t-tests, Intraclass Correlation Coefficients (ICC), Minimal Difference (MD) and Standard Error of Measurement (SEM) using the model two approach as recommend by Weir.[14] Paired samples t-tests were used to identify differences between sets or sessions for all measures across the TOP, MID, and BOT segments of the movement, while the level of agreement between sets and sessions was determined based on ICCs. Set to set comparisons were derived from visit two while comparing each variable, as determined by AR and FRV, between Set 1 to Set 2. To determine inter-session reliability, the set with the highest MV, as determined by AR and FRV, on Day 1 and on Day 2 were compared to determine inter-session reliability. Classification for reliability was identified by the recommendations of Koo et al,[15] with ICCs > 0.90 deemed 'Excellent', ICCs of 0.75-0.9 classified as 'Good', values between 0.5-0.75 identified as 'Moderate' and, ICCs < 0.5 classified as 'Poor'. Statistical significance was set to $p \leq 0.05$.

Results

Beginning with inter-set reliability, AR tended to produce better ICCs when compared to FRV, therefore AR data are presented in Table 1 (FRV data are provided in Supplemental Table 1). Excellent ICCs were present for MV, PV and DUR at most intensities in each segment, with the only exception of MV at 30% which presented good ICCs in BOT. Notably for PV, there was a significant difference between sets at 30% in MID (p=0.036). For DUR, good ICCs were present at 30% and 50% BOT, with a significant difference between sets (p=0.010) at 30%. Excellent ICCs and a significant difference between sets (p=0.049) were exhibited for DUR at 70% within BOT. Good ICCs were also present for DUR at 70% for MID.

When using FRV, good to excellent ICCs were present in MV, PV, and DUR at 30% across each segment. For MV and PV, good to excellent ICCs were present at 50% in all segments, whereas DUR exhibited varying reliability across segments. For DUR at 50%, excellent ICCS were revealed at TOP and MID, whereas moderate ICCs were observed at BOT. Good to excellent ICCs were indicated for all measures and segments during 60% and 70%.

As for inter-session reliability, AR also tended to produce stronger ICCs when compared to FRV; therefore, AR data are presented in Table 2 (FRV data are provided in Supplemental Table 2). MV and PV revealed excellent ICCs at 30% across the three segments, while DUR at BOT showed good ICCs. Good to excellent ICCs were displayed for MV and PV across segments at 50%; however DUR showed good to moderate ICCs for all segments. Moderate to poor ICCs were present in MV, PV and DUR during 60% and 70% across all segments of the movement.

When using FRV, variable ICCs were exhibited across measures and segments. Good to excellent ICCs were present for MV and PV at 30% in each segment, while moderate to good ICCs were present for DUR in all segments. Moderate to poor ICCs were reported for most measures in all segments at 50%, with the only exception of TOP which demonstrated good to excellent ICCs for MV, PV and DUR. Notably, there was a significant difference between sessions (p=0.001) for PV at 50% within MID. Poor ICCs were exhibited for all measures across each segment at 60%, while moderate to poor ICCs were present in all measures within each segment at 70%.

Table 1. Inter-set reliability of the HUMAC360 LPT determined by the Average Repetition during ascending intensities across segmental thirds of the bench press.

		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%**
BOT	**$ICC_{2,k}$**	0.869	0.934	0.974	0.944	0.902	0.958	0.963	0.954	0.827	0.870	0.960	0.936
	$SEM_{2,k}$	0.043	0.024	0.012	0.016	0.064	0.027	0.019	0.019	0.021	0.015	0.010	0.015
	p-value	0.122	0.371	0.558	0.241	0.137	0.638	0.553	0.297	***0.010****	0.283	0.075	***0.049****
	MD	0.10	0.06	0.03	0.04	0.15	0.07	0.05	0.05	0.01	0.01	0.00	0.01
Mean(SD)	**Set 1**	0.45 (0.08)	0.43 (0.05)	0.40 (0.06)	0.35 (0.04)	0.84 (0.15)	0.71 (0.08)	0.62 (0.07)	0.49 (0.06)	0.17 (0.03)	0.19 (0.02)	0.22 (0.03)	0.28 (0.04)
	Set 2	0.48 (0.08)	0.42 (0.07)	0.40 (0.51)	0.34 (0.04)	0.87 (0.13)	0.70 (0.10)	0.61 (0.07)	0.48 (0.06)	0.15 (0.03)	0.20 (0.03)	0.22 (0.03)	0.29 (0.04)
MID	**$ICC_{2,k}$**	0.928	0.966	0.935	0.937	0.947	0.967	0.906	0.926	0.940	0.968	0.966	0.897
	$SEM_{2,k}$	0.077	0.031	0.028	0.024	0.063	0.035	0.033	0.029	0.008	0.006	0.006	0.012
	p-value	0.062	0.734	0.190	0.371	***0.036****	0.480	0.118	0.457	0.057	0.928	0.593	0.303
	MD	0.17	0.08	0.07	0.06	0.17	0.09	0.09	0.08	0.02	0.01	0.01	0.03
Mean(SD)	**Set 1**	1.01 (0.21)	0.83 (0.10)	0.70 (0.07)	0.55 (0.06)	1.12 (0.25)	0.92 (0.12)	0.77 (0.08)	0.61 (0.07)	0.10 (0.02)	0.12 (0.02)	0.15 (0.02)	0.20 (0.02)
	Set 2	1.06 (0.18)	0.83 (0.13)	0.69 (0.08)	0.54 (0.06)	0.17 (0.22)	0.91 (0.14)	0.75 (0.09)	0.60 (0.07)	0.09 (0.02)	0.12 (0.02)	0.15 (0.02)	0.20 (0.02)
TOP	**$ICC_{2,k}$**	0.973	0.982	0.952	0.929	0.958	0.975	0.918	0.945	0.934	0.966	0.966	0.925
	$SEM_{2,k}$	0.047	0.025	0.034	0.025	0.077	0.033	0.041	0.030	0.019	0.013	0.012	0.012
	p-value	0.374	0.388	0.091	0.910	0.063	0.559	0.066	0.489	0.218	0.897	0.163	0.889
	MD	0.13	0.07	0.08	0.07	0.18	0.09	0.09	0.08	0.04	0.03	0.03	0.03
Mean (SD)	**Set 1**	0.74 (0.21)	0.66 (0.13)	0.59 (0.09)	0.51 (0.07)	1.14 (0.28)	0.94 (0.14)	0.80 (0.10)	0.66 (0.09)	0.24 (0.05)	0.24 (0.05)	0.26 (0.04)	0.28 (0.03)
	Set 2	0.76 (0.19)	0.65 (0.13)	0.57 (0.10)	0.51 (0.06)	1.19 (0.24)	0.93 (0.16)	0.78 (0.10)	0.65 (0.08)	0.23 (0.04)	0.24 (0.04)	0.26 (0.05)	0.28 (0.02)

ICC: Intraclass Correlation Coefficient; *SD:* Standard Deviation; *MD:* Minimal Difference; *SEM:* Standard Error of Measurement *TOP*: Top phase of movement; *MID*: Middle phase of movement; *BOT*: Bottom phase of movement; *Denotes Significance

Table 2. Inter-session reliability of the HUMAC360 LPT determined by the Average Repetition during ascending intensities across segmental thirds of the bench press.

		Mean Velocity ($m \cdot s^{-1}$)				**Peak Velocity ($m \cdot s^{-1}$)**				**Movement Duration (s)**			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
BOT	**$ICC_{2,k}$**	0.090	0.841	0.647	0.598	0.940	0.906	0.577	0.587	0.860	0.720	0.506	0.620
	$SEM_{2,k}$	0.032	0.033	0.044	0.042	0.045	0.036	0.066	0.051	0.015	0.019	0036	0.034
	p-value	0.455	0.207	0.836	0.919	0.953	0.770	0.422	0.732	0.492	0.408	0.970	0.970
	MD	0.08	0.08	0.10	0.10	0.13	0.10	0.15	0.12	0.04	0.04	0.08	0.08
Mean(SD)	**Day 1**	0.48 (0.08)	0.44 (0.06)	0.40 (0.05)	0.35 (0.05)	0.88 (0.13)	0.72 (0.09)	0.61 (0.07)	0.50 (0.06)	0.15 (0.03)	0.19 (0.02)	0.22 (0.03)	0.28 (0.03)
	Day 2	0.47 (0.05)	0.43 (0.05)	0.40 (0.05)	0.35 (0.04)	0.88 (0.12)	0.73 (0.07)	0.63 (0.01)	0.50 (0.05)	0.15 (0.02)	0.19 (0.02)	0.22 (0.03)	0.28 (0.04)
MID	**$ICC_{2,k}$**	0.947	0.904	0.564	0.476	0.949	0.901	0.471	0.513	0.927	0.852	0.734	0.640
	$SEM_{2,k}$	0.059	0.045	0.071	0.059	0.071	0.054	0.085	0.063	0.008	0.010	0.016	0.019
	p-value	0.597	0.436	0.524	0.733	0.447	0.226	0.374	0.467	0.328	0.431	0.317	0.974
	MD	0.16	0.12	0.16	0.13	0.19	0.13	0.19	0.14	0.02	0.02	0.03	0.04
Mean(SD)	**Day 1**	1.07 (0.18)	0.85 (0.11)	0.71 (0.08)	0.62 (0.08)	1.18 (0.22)	0.93 (0.13)	0.78 (0.08)	0.69 (0.08)	0.09 (0.02)	0.12 (0.02)	0.15 (0.02)	0.19 (0.02)
	Day 2	1.08 (0.18)	0.86 (0.08)	0.72 (0.06)	0.63 (0.06)	1.20 (0.23)	0.96 (0.10)	0.80 (0.07)	0.71 (0.07)	0.09 (0.02)	0.11 (0.01)	0.14 (0.01)	0.19 (0.02)
TOP	**$ICC_{2,k}$**	0.953	0.943	0.580	0.745	0.956	0.891	0.431	0.632	0.948	0.893	0.564	0.729
	$SEM_{2,k}$	0.060	0.042	0.081	0.044	0.075	0.063	0.105	0.069	0.016	0.021	0.047	0.019
	p-value	0.501	0.214	0.799	0.178	0.128	0.119	0.503	0.062	0.467	0.336	0.681	0.328
	MD	0.16	0.10	0.19	0.10	0.18	0.15	0.23	0.14	0.04	0.05	0.11	0.04
Mean (SD)	**Day 1**	0.76 (0.91)	0.67 (0.13)	0.59 (0.09)	0.52 (0.07)	1.19 (0.24)	0.95 (0.15)	0.83 (0.10)	0.66 (0.09)	0.23 (0.04)	0.24 (0.05)	0.26 (0.04)	0.27 (0.02)
	Day 2	0.79 (0.20)	0.69 (0.14)	0.60 (0.01)	0.54 (0.04)	1.22 (0.25)	0.99 (0.11)	0.83 (0.09)	0.77 (0.05)	0.22 (0.05)	0.23 (0.03)	0.26 (0.05)	0.27 (0.02)

ICC: Intraclass Correlation Coefficient; *SD:* Standard Deviation; *MD:* Minimal Difference; *SEM:* Standard Error of Measurement *TOP*: Top phase of movement; *MID*: Middle phase of movement; *BOT*: Bottom phase of movement.

Discussion

As hypothesized, the HUMAC360 was able to produce reliable inter-set data for MV, PV and DUR across the segmental thirds; however, inter-session reliability varied. Inter-set data displayed good to excellent ICCs with improvements in SEMs and MDs as intensity increased for all measures within each segment of the movement (Table 1). Session to session measurements of MV, PV and DUR during lower intensities revealed moderate to excellent ICCs while higher intensities demonstrated poor to moderate ICCs with SEMs and MDs largely inconsistent between intensities and across segments. Lastly, there tended to be improved reliability, as measured by ICCs and SEMs, when using AR compared to FRV, indicating AR is preferrable for repeated measurements.

Previous investigations have reported similar inter-set reliability compared to our findings when using the ChronoJump and Speed4lift LPTs[4] or HUMAC360 LPT[10] across the full movement of the bench press. The ChronoJump, Speed4lift, and HUMAC360 revealed good to excellent ICCs when assessing MV and PV at a wide range of intensities.[4,10] When adopting a segmental approach, the HUMAC360 displayed improved SEMs as intensities increased, which are similar findings when observing the full movement.[10] We suspect the SEMs improved due to the hyperbolic nature of the force-velocity relationship,[16] such that the inverse relationship may have led to possible increases in repetition duration and resulted in more measurements obtained at the higher intensities. Moreover, repetitions completed at lower intensities may allow for a broader range of velocities to be used by participants, which may also increase the variability. Given that SEM is based on the standard deviation of the measure and reliability coefficient, it is likely the increases in variability are due to a reduced number of measurements during each segment when compared to the entire movement. It should also be noted that the segmental approach of this investigation resulted in larger SEMs than those reported for the full movement of the bench press.[10]

Prior use of the segmental approach during the back squat demonstrated similar trends of inter-set reliability with excellent ICCs across intensities and similar SEM and MD trends within segments.[10] For both investigations, SEMs and MDs were greatest at MID when compared to TOP and BOT, which may have been driven by the short duration of MID relative to the other segments.[17] When comparing SEMs between the full and segmental approach of the back squat, SEMs and MDs within the segmental approach were greater than the full approach,[17,17] which notably was a similar observation found when comparing our findings to those within the full movement of the bench press.[10] These trends may again be due to the reduced number of observations within segments, therefore suggesting a flaw with the segmental approach. It should be noted that SEMs in our investigation were also larger than those reported in Pelka et al[17] who also reported a longer duration in each of the segments, further suggesting that the variability in SEMs is likely influenced by the movement duration. Therefore, a higher frequency may be required to increase the number of measures per segment and allow for similar comparisons of measures collected during a full ROM.

Prior reports analyzing inter-session reliability demonstrated moderate to good ICCs across various intensities [10-90% 1RM[2] and 20-90% 1RM].[1] The Tendo Weightlifting Analyzer, however, displayed no discernible change in ICCs across intensities[2] while ICCs improved as intensities increased when using the GymAware PowerTool.[1] Moreover, MDs while using the Tendo Weightlifting Transducer Analyzer improved during ascending intensities and SEMs for both LPTs improved.[1,2] Conversely, our data demonstrated reduced ICCs from excellent to poor as intensities increased within each segment for all measures with no recognizable pattern for changes in SEMs and MDs across intensities, similar to a prior report with the HUMAC360 during the bench press.[10] Notably, the Tendo Weightlifting Analyzer reported lower SEMs[2] while the Gym Aware Power Tool reported higher SEMs[1] compared to the current investigation. These differences derived from the Tendo Weightlifting Analyzer and GymAware PowerTool when compared to the HUMAC360 are likely present due to the diverse sampling features and approaches of each LPT. The Tendo Weightlifting Analyzer allows for sampling frequency to vary dependent on observed movements[18] whereas the HUMAC360 and the GymAware PowerTool frequency remained static; moreover, the GymAware PowerTool utilized a lower sampling rate (50Hz)[1] compared to the HUMAC360. Thus, suggesting that selection and application of particular sampling frequencies is crucial when analyzing various movements.

Pelka and colleagues[17] also demonstrated similar results for inter-session reliability across intensities for segments of the squat exercise when compared to our results. Within our investigation, the HUMAC360 revealed good to excellent ICCs during lower intensities and reduced ICCs (poor to moderate) at higher intensities in each segment (Table 2), although ICCs for the segmental squat remained higher (excellent to good).[17] Interestingly, there were no discernable trends in the changes for SEMs within TOP and MID, though BOT seemed to worsen as intensity increased for both the segmental squat[17] and segmental bench. Notably, Pelka et al,[17] reported higher absolute SEMs for all segments and intensities of the squat when compared to the bench press in this investigation, possibly due to the greater velocities for the squat when compared to the bench press. Finally, both the segmental squat and bench press displayed reduced ICCs for inter-session reliability when compared to inter-set,[17] similar to others that assessed both inter-session and inter-set ICCs for the full movement of the power clean,[19] bench press,[10] and the squat.[20] Therefore, our observed reductions in reliability can likely be attributed to general variability that may occur with day to day observations.[21]

A limitation within our investigation is the variable training status amongst the participants, which was self-reported, and only required six months of prior resistance exercise experience. Therefore, considerable variation in the experience of individuals that participated was present, and it is likely that those with less experience were not as well accustomed to the bench press movement at the full range of intensities we used. This lack of familiarity may have led to the diminished inter-session reliability as well as with the overall larger SEMs for inter-set reliability in our investigation. Future investigations should consider using a stricter training status inclusion criterion as others have demonstrated strong inter-set[4] and inter-session[2] comparisons when using individuals who were well trained.

Future investigations should examine the ability of using a LPT over segmented thirds to observe functional performance recovery from resistance exercise. Interestingly, a previous investigation demonstrated no changes in movement velocity of the bench press despite the presence of indirect markers of muscle damage (creatine kinase concentrations) following resistance exercise.[3] Given that Van Den Tillaar and Saeterbakken[22] demonstrated significant variation in movement velocity based around the sticking region, the lack of change in velocity reported by Mangine and colleagues[3] may have occurred due to examining velocities over the full ROM. Utilizing segmental observations may allow for a more granular analysis of the changes in velocity that may be more sensitive to muscular damage. Moreover, segmentation of the movement may allow for coaches to observe the possible onset of fatigue while training and make appropriate adjustments to an athlete's program between sessions. Doing so will afford coaches the opportunity to prevent the presence of fatigue, provide adequate recovery and avoid possible implications that are accompanied by chronic training bouts.

Applying segmental observations of the bench press will enable coaches to observe critical portions of the movement and effectively consider various influences impacting VBT principles. Moreover, adoption of the segmental approach can afford practitioners to adequately observe performance and strength adaptations given the inclusion of observing movement velocity at the most critical portion of the movement, specifically the sticking region. Aside from utilizing an LPT for VBT, it has also been implemented to provide insight regarding muscular fatigue and effort. However, given the large variation in velocity over the full ROM, most notably due to the sticking region, the onset of fatigue at the most consequential portions of the movement may be overlooked. Moreover, this oversight may lead to inaccurate prescriptions and increase the risk of improper recovery. Therefore, coaches should consider utilizing an LPT that allows for segmental observations, so that the changes in velocity at various points of the movement may be made.

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Supplemental Table 1. Inter-set reliability of the HUMAC360 LPT determined by the Fastest Repetition during ascending intensities across segmental thirds of the bench press.

		Mean Velocity ($m \cdot s^{-1}$)				**Peak Velocity ($m \cdot s^{-1}$)**				**Movement Duration (s)**			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
BOT	**$ICC_{2,1}$**	0.814	0.826	0.943	0.905	0.786	0.867	0.923	0.836	0.785	0.697	0.827	0.831
	$SEM_{2,1}$	0.049	0.041	0.019	0.022	0.093	0.051	0.032	0.039	0.017	0.020	0.021	0.019
	p-value	0.326	0.558	0.479	0.840	0.059	0.775	***0.008****	0.388	0.164	1.000	0.270	1.000
	MD	0.09	0.08	0.03	0.04	0.16	0.10	0.05	0.07	0.03	0.04	0.04	0.03
Mean (SD)	**Set 1**	0.49 (0.04)	0.46 (0.05)	0.42 (0.06)	0.36 (0.05)	0.87 (0.14)	0.74 (0.07)	0.65 (0.08)	0.53 (0.07)	0.15 (0.02)	0.18 (0.02)	0.22 (0.03)	0.26 (0.03)
	Set 2	0.50 (0.08)	0.45 (0.08)	0.42 (0.05)	0.36 (0.05)	0.91 (0.13)	0.73 (0.11)	0.63 (0.08)	0.52 (0.06)	0.15 (0.02)	0.18 (0.03)	0.21 (0.03)	0.26 (0.03)
MID	**$ICC_{2,1}$**	0.868	0.883	0.897	0.836	0.892	0.876	0.815	0.805	0.863	0.916	0.871	0.820
	$SEM_{2,1}$	0.101	0.061	0.037	0.044	0.113	0.073	0.059	0.052	0.012	0.010	0.011	0.014
	p-value	0.176	0.611	***0.001****	0.120	0.167	0.751	***0.006****	0.203	0.232	0.486	0.210	0.249
	MD	0.19	0.12	0.05	0.08	0.21	0.14	0.09	0.10	0.02	0.02	0.02	0.02
Mean (SD)	**Set 1**	1.07 (0.20)	0.86 (0.10)	0.75 (0.07)	0.60 (0.08)	1.18 (0.25)	0.95 (0.12)	0.83 (0.09)	0.67 (0.08)	0.09 (0.02)	0.12 (0.02)	0.14 (0.02)	0.17 (0.02)
	Set 2	1.11 (0.18)	0.87 (0.14)	0.72 (0.08)	0.59 (0.06)	1.22 (0.23)	0.96 (0.16)	0.79 (0.10)	0.65 (0.07)	0.09 (0.02)	0.11 (0.02)	0.14 (0.02)	0.18 (0.02)
TOP	**$ICC_{2,1}$**	0.922	0.930	0.827	0.868	0.881	0.882	0.769	0.851	0.858	0.930	0.961	0.811
	$SEM_{2,1}$	0.081	0.050	0.060	0.037	0.098	0.080	0.071	0.049	0.017	0.016	0.012	0.018
	p-value	0.974	0.599	0.700	0.812	0.329	0.913	***0.005****	0.606	0.544	0.879	0.168	0.236
	MD	0.16	0.10	0.11	0.07	0.26	0.16	0.11	0.09	0.04	0.03	0.02	0.03
Mean (SD)	**Set 1**	0.80 (0.21)	0.70 (0.12)	0.63 (0.09)	0.55 (0.08)	1.20 (0.29)	0.97 (0.14)	0.86 (0.10)	0.71 (0.10)	0.27 (0.04)	0.23 (0.04)	0.24 (0.04)	0.27 (0.03)
	Set 2	0.80 (0.19)	0.69 (0.14)	0.60 (0.10)	0.55 (0.05)	1.24 (0.25)	0.97 (0.18)	0.82 (0.11)	0.70 (0.07)	0.22 (0.04)	0.23 (0.04)	0.25 (0.01)	0.26 (0.02)

ICC: Intraclass Correlation Coefficient; *SD:* Standard Deviation; *MD*: Minimal Difference; *SEM*: Standard Error of Measurement; *TOP*: Top phase of movement; *MID*: Middle phase of movement; *BOT*: Bottom phase of movement. *Denotes Significance.

Supplemental Table 2. Inter-session reliability of the HUMAC360 LPT determined by the Fastest Repetition during ascending intensities across segmental thirds of the bench press.

		Mean Velocity ($m•s^{-1}$)				Peak Velocity ($m•s^{-1}$)				Movement Duration (s)			
		30%	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**	**30%**	**50%**	**60%**	**70%**
BOT	**$ICC_{2,1}$**	0.929	0.740	0.449	0.350	0.915	0.640	0.223	0.044	0.744	0.498	0.338	0.178
	$SEM_{2,1}$	0.028	0.045	0.060	0.055	0.049	0.074	0.102	0.102	0.020	0.020	0.044	0.043
	p-value	0.219	0.837	0.416	0.307	0.688	0.606	0.410	0.910	0.817	1.000	0.663	0.919
	MD	0.07	0.09	0.11	0.10	0.09	0.14	0.19	0.20	0.04	0.03	0.08	0.09
Mean (SD)	**Day 1**	0.51 (0.08)	0.47 (0.06)	0.42 (0.05)	0.37 (0.04)	0.91 (0.11)	0.75 (0.09)	0.62 (0.08)	0.54 (0.07)	0.15 (0.02)	0.18 (0.01)	0.22 (0.03)	0.26 (0.03)
	Day 2	0.50 (0.06)	0.46 (0.06)	0.43 (0.05)	0.38 (0.04)	0.91 (0.12)	0.76 (0.07)	0.65 (0.07)	0.53 (0.07)	0.15 (0.03)	0.18 (0.02)	0.21 (0.03)	0.26 (0.04)
MID	**$ICC_{2,1}$**	0.836	0.690	0.417	0.269	0.819	0.725	0.283	0.374	0.774	0.770	0.498	0.322
	$SEM_{2,1}$	0.099	0.086	0.077	0.087	0.133	0.092	0.100	0.085	0.015	0.014	0.021	0.026
	p-value	0.584	0.809	0.603	0.465	0.551	***0.001****	0.731	0.229	0.106	0.150	0.497	0.584
	MD	0.16	0.12	0.16	0.13	0.26	0.18	0.19	0.17	0.02	0.02	0.04	0.05
Mean (SD)	**Day 1**	1.12 (0.17)	0.89 (0.12)	0.75 (0.07)	0.62 (0.08)	1.24 (0.22)	0.98 (0.14)	0.83 (0.09)	0.69 (0.08)	0.09 (0.02)	0.11 (0.02)	0.14 (0.02)	0.17 (0.02)
	Day 2	1.13 (0.17)	0.90 (0.09)	0.76 (0.06)	0.63 (0.06)	1.26 (0.22)	0.99 (0.10)	0.84 (0.07)	0.71 (0.07)	0.08 (0.02)	0.11 (0.01)	0.13 (0.01)	0.17 (0.19)
TOP	**$ICC_{2,1}$**	0.887	0.906	0.425	0.520	0.832	0.753	0.279	0.683	0.869	0.932	0.461	0.610
	$SEM_{2,1}$	0.093	0.054	0.089	0.070	0.146	0.102	0.106	0.090	0.021	0.013	0.034	0.026
	p-value	0.665	0.593	0.639	0.162	0.159	0.488	0.463	0.052	0.132	0.860	0.315	0.647
	MD	0.18	0.10	0.17	0.13	0.27	0.20	0.02	0.16	0.03	0.02	0.06	0.05
Mean (SD)	**Day 1**	0.83 (0.19)	0.71 (0.13)	0.64 (0.10)	0.56 (0.08)	1.24 (0.25)	1.02 (0.16)	0.87 (0.10)	0.72 (0.10)	0.22 (0.04)	0.23 (0.04)	0.24 (0.04)	0.26 (0.03)
	Day 2	0.85 (0.19)	0.72 (0.11)	0.65 (0.05)	0.58 (0.05)	1.29 (0.24)	1.02 (0.11)	0.89 (0.06)	0.76 (0.08)	0.21 (0.03)	0.22 (0.03)	0.24 (0.01)	0.26 (0.02)

ICC: Intraclass Correlation Coefficient; *SD:* Standard Deviation; *MD:* Minimal Difference; *SEM:* Standard Error of Measurement; TOP: Top phase of movement; *MID*: Middle phase of movement; *BOT*: Bottom phase of movement. *Denotes Significance