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The Criterion Validity and Between-Day Reliability of the Perch for Measuring Barbell Velocity During Commonly Used Resistance Training Exercises

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Abstract

Weakley, J, Munteanu, G, Cowley, N, Johnston, R, Morrison, M, Gardiner, C, Pérez-Castilla, A, and García-Ramos, A. The criterion validity and between-day reliability of the Perch for measuring barbell velocity during commonly used resistance training exercises. *J Strength Cond Res* XX(X): 000–000, 2022—This study aimed to assess the criterion validity and between-day reliability (accounting for technological and biological variability) of mean and peak concentric velocity from the Perch measurement system. On 2 testing occasions, 16 subjects completed repetitions at 20, 40, 60, 80, 90, and 100% of 1-repetition maximum in the free-weight barbell back squat and bench press. To assess criterion validity, values from the Perch and a 3-dimensional motion capture system (criterion) were compared. Technological variability was assessed by determining whether the differences between the Perch and criterion for each load were comparable for both testing sessions, whereas between-day reliability with both technological and biological variability was calculated from Perch values across days. Generalized estimating equations were used to calculate R^2 and root mean square error, whereas Bland-Altman plots assessed magnitude of difference between measures. To support monitoring of athletes over time, standard error of measurement and minimum detectable changes (MDC) were calculated. There was excellent agreement between the Perch and criterion device, with mean velocity in both exercises demonstrating a mean bias ranging from -0.01 to 0.01 $m \cdot s^{-1}$. For peak velocity, Perch underestimated velocity compared with the criterion ranging from -0.08 to -0.12 $m \cdot s^{-1}$ for the back squat and -0.01 to -0.02 $m \cdot s^{-1}$ for the bench press. Technological variability between-days were all less than the MDC. These findings demonstrate that the Perch provides valid and reliable mean and peak concentric velocity outputs across a range of velocities. Therefore, practitioners can confidently implement this device for the monitoring and prescription of resistance training.

Key Words: back squat, bench press, velocity-based training, monitoring, motion capture

Introduction

Exercise velocity is an important consideration when programming resistance training (21). Specifically, mean and peak velocity during training is commonly used to guide exercise prescription (9,10), mitigate or accentuate fatigue responses (6,25), enhance motivation and competitiveness (27,31), and monitor changes in physical performance (30,32,33). By monitoring velocity during resistance training, practitioners can accurately reproduce fatigue responses (22), while also closely controlling the kinetic and kinematic outputs that are produced (16,24). This is beneficial because it is well-established that greater velocity loss during resistance training can induce increased fatigue and can mediate changes in physical qualities. However, if using velocity to guide resistance training, it is important to consider the accuracy and reliability of the tools that are being used (23).

During resistance training, mean and peak velocity are often measured through the use of linear transducers (1,11), inertial measurement units (12,17), and optic lasers (19). Because there are differences between brands and the type of device, a wide range of validity and reliability values have been provided throughout the literature (23). Linear transducers and optic lasers are accurate; however, having a device attached to a barbell while exercising may be disconcerting for an athlete. Additionally, while inertial measurement units are often less expensive than other types of monitoring device, they have increased the risk of error (23). To avoid these issues, the Perch device (Catalyft Labs, Cambridge, MA) has recently been developed, which uses a camera system to monitor barbell displacement with respect to time, which allows the velocity to be calculated. However, the validity and reliability of this device's measures during commonly used resistance training exercises has not yet been established.

To support resistance training methods that rely on real-time information (e.g., velocity-based training (2,21)), it is essential to have technology that demonstrates acceptable levels of validity. Furthermore, if an athlete wishes to use a device across multiple training sessions to monitor their performance, it is important to

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understand the device's reliability. However, when establishing reliability, it is important to distinguish between technological variation (i.e., error associated with the technology) and biological variation (i.e., error introduced from human sources). This has been discussed several times recently within the scientific literature (4,19), with a review calling for greater distinction of these forms of variability (23). Therefore, the aims of this study were to (a) establish the criterion validity of mean and peak concentric velocity outputs from the Perch device during the free-weight barbell back squat and bench press at a range of intensities and (b) assess the between-day reliability accounting for technological and biological variability of the Perch device.

Methods

Experimental Approach to the Problem

Criterion validity and between-day reliability of the Perch device was assessed across 2 testing sessions with 3–7 days between testing. Completed in a biomechanics laboratory, subjects performed several repetitions of the free-weight barbell back squat and bench press across 20–100% of each subject's 1-repetition maximum (1RM). During testing, each repetition was simultaneously recorded by the Perch measurement system and by a 3-dimensional (3D) motion capture system (i.e., the criterion measure). To assess validity, mean and peak concentric velocity of each repetition from the Perch and criterion were compared. To assess the between-day technological variability, the error between the Perch and criterion for each repetition on each day was compared (i.e., the error from testing occasion one *vs* the error from testing occasion two) because this isolates the technological error on each occasion. Finally, to assess the between-day reliability accounting for the technological and biological variability, values from the Perch on day 1 were compared with values on day 2.

Subjects

Sixteen subjects (12 men and 4 women, age: 25 ± 3 years, body mass: 82 ± 15 kg, height: 176 ± 11 cm; Participants were all over 18. Participants were aged between 20-32. This data is supplied as Mean ± *SD*) who had at least 2-year resistance training experience in the back squat and bench press volunteered to participate in this study (28). All subjects were required to be injury free, abstain from caffeine on the day of testing, and regularly complete at least 2 resistance training sessions per week. Subjects were informed of the experimental procedures, provided the opportunity to ask questions, and provided written informed consent. This project was approved by the Australian Catholic University Human Research Ethics Committee (Ethics number: 2019-131H).

Procedures

Subjects attended a biomechanics laboratory on 2 occasions that were separated by 3–7 days. All testing was completed at the same time of day for each subject (±1 hour), with consent and familiarization occurring on the first testing occasion. Although technique of the tested movements has previously been outlined (13,29), the back squat was completed with the bar resting on the upper trapezius with subjects required to lower themselves so that the tops of their thighs were parallel with the floor and to maintain contact with the ground at all times. The bench press was completed with hands positioned at a self-selected width with the bar lowered to the chest and returned to a locked-out position. During each repetition, subjects were asked to control the bar on the eccentric portion of the movement and were encouraged to be as forceful and as powerful as possible on the concentric phase (27,31). At least 3-minutes rest was provided between each set. Consistent with previous validity and reliability research (12), all exercise loads were calculated from recent training records.

On both testing occasions, subjects were required to complete a 15-minute warm-up, which consisted of dynamic stretching and exercise-specific movements (e.g., push-ups and body weight squats). Once subjects had warmed up, they were required to complete 3 repetitions of 20, 40, 60, and 80% of 1RM, whereas 2 repetitions were completed with 90%, and a final repetition at their 1RM load, for both the back squat and bench press. To quantify the mean and peak concentric velocity, a Perch device was placed in front of the subject at a height of 2.1 m on the crossbar of the exercise rack used. Briefly, the Perch device is a camera-based system that can detect and quantify the displacement of a barbell. Using this information, the Perch camera system sends information to a tablet, which presents kinetic and kinematic information. The camera system is made to sit on the cross bar of a lifting rack and is held in place by Velcro straps. The device can be moved (i.e., it can be placed on different lifting racks); however, within this study, it was fastened to the same rack throughout. Additionally, a reflective marker was placed in the direct center of either side of an Olympic barbell (Eleiko Performance Weightlifting Bar, Eleiko, Halmstad, Sweden). The Perch device was then connected through Bluetooth to a Samsung Galaxy tablet (Samsung Electronics, Suigen, South Korea) that was running the Perch app (version 2.1.4) that recorded all values.

Marker trajectories were recorded at 200 Hz by a 12-camera 3D motion analysis system (Vicon Vantage, Vicon Motion Systems, Oxford, United Kingdom) using the Vicon Nexus software package (v2.12; Vicon, Oxford, United Kingdom) after the capture space was calibrated in accordance with manufacturer recommendations. Data were filtered using a low-pass Butterworth filter (zero lag) with a cutoff frequency of 6 Hz. Using the processed trajectories, a centroid was created, and velocities were derived using Vicon Nexus before the data were exported to MATLAB (MathWorks, Nattick, MA), where the mean and peak velocity of the markers during the concentric phase of the movements was determined. The start of the concentric phase of each repetition was determined as the first frame in which the marker displayed a positive vertical velocity following the eccentric phase. Additionally, the end of the concentric phase was identified as the first frame in which the marker displayed a negative vertical velocity after the end of the concentric lifting phase. Mean and peak vertical velocity were subsequently determined from averaging velocity data over

Table 1

Goodness of fit and regression equations obtained from the generalized estimating equations for the relationship between Perch and Vicon for mean and peak velocities during the back squat and bench press exercises.*

Variable	R^2	RMSE	Equation to predict criterion velocity
Back squat			
Mean velocity	0.96	0.05	$y = 0.02394 + (0.97738 \times X)$
Peak velocity	0.97	0.04	$y = 0.1258 + (0.9784 \times X)$
Bench press			
Mean velocity	0.99	0.02	$y = -0.01137 + (1.00198 \times X)$
Peak velocity	0.98	0.04	$y = 0.0229 + (0.9924 \times X)$

*RMSE = root mean square error.

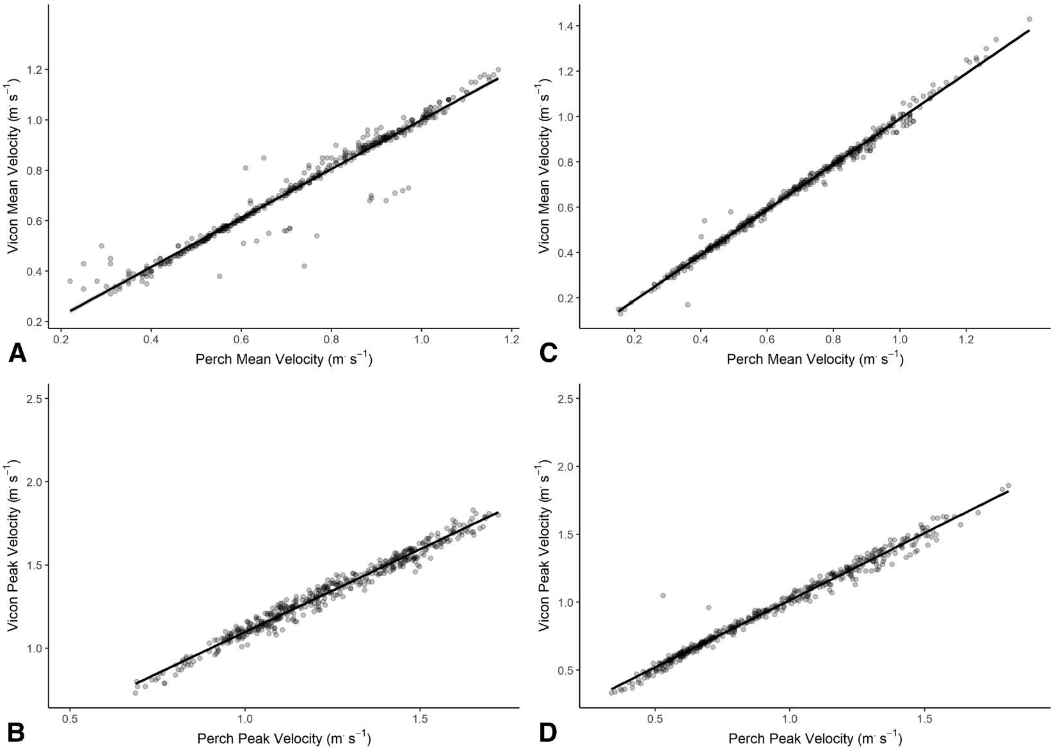

Figure 1. Scatter plots for mean and peak velocity in the back squat (A and B) and bench press (C and D) from the practical (Perch) and criterion (Vicon) devices.

the concentric phase and identifying the greatest value in the concentric phase, respectively.

Statistical Analyses

All statistical analyses were done in RStudio (version 1.1.463) using R programming language (version 4.0.5, Boston, MA). The relationship between criterion and Perch measures (i.e., validity) were assessed through regression analysis. Because of the dependency arising from repeated measures on the same individual (i.e., multiple repetitions at each intensity), generalized linear models were fit with generalized estimating equations (GEE) using the *geepack* package and an exchangeable correlation structure, determined by the structure that provided the lowest quasi-likelihood information criterion (QIC). To assess the strength of the relationship and goodness of fit, a marginal R^2 method (34) and root-mean-square error (RMSE) were calculated. Bland-Altman plots were also used to assess the magnitude and direction of differences between measures using a mixed effects approach to account for the repeated measures on individuals as described previously using the *nlme* package in R (14,15), where subject was included as a random intercept and intensity was included as a fixed effect. Subsequently, appropriately weighted mean bias and limits of agreement were generated for each variable from the linear mixed models.

Because of the difficulties in measuring test-retest reliability of a device on 2 separate days, where technological error cannot be isolated as a result of subject variability (i.e., biological variation), validity assessments were performed on 2 days to determine if the difference between devices was consistent. To assess differences to criterion between days, GEE models were built for each dependent variable. Finally, to set thresholds required for interpreting changes over time, *SEM*, which accounts for both biological and technological error, along with the minimum detectable change (MDC) were calculated (18). Data are presented as means ± *SD*s and significance was set at $p < 0.05$ a priori.

Results

Differences to Criterion

The results of the GEE models between the Perch and criterion measures of bar velocity in both the back squat and bench press are displayed in Table 1. For both velocity variables, the Perch device explained between 96 and 99% of the variation in the criterion measure, with slightly better performance for mean velocity over peak velocity in both exercises (Figure 1). The RMSE for all variables was between 0.02 and 0.05 $\mathrm{m \cdot s^{-1}}$; this highlights excellent agreement between devices.

The results of the Bland-Altman analysis (Figure 2 and Table 2) highlight the mean bias for both mean and peak velocity compared with the criterion for both exercises. Mean velocity showed slightly better agreement with mean bias ranging from −0.01 to 0.01 $\mathrm{m \cdot s^{-1}}$, with no difference across intensities. For peak velocity, the Perch device underestimated velocity compared with the criterion; however, mean bias ranged from −0.08 to −0.12 $\mathrm{m \cdot s^{-1}}$ for the back squat and −0.01 to −0.02 $\mathrm{m \cdot s^{-1}}$ for the bench press, with no difference across intensities.

Difference in Agreement Across Days

There was no significant difference between days for the difference to criterion for mean velocity ($p = 0.11$ for back squat and $p = 0.95$ for bench press) or peak velocity ($p = 0.052$ for bench press). However, there was a significant difference between day 1 and day 2 for peak velocity in the back squat ($p =$

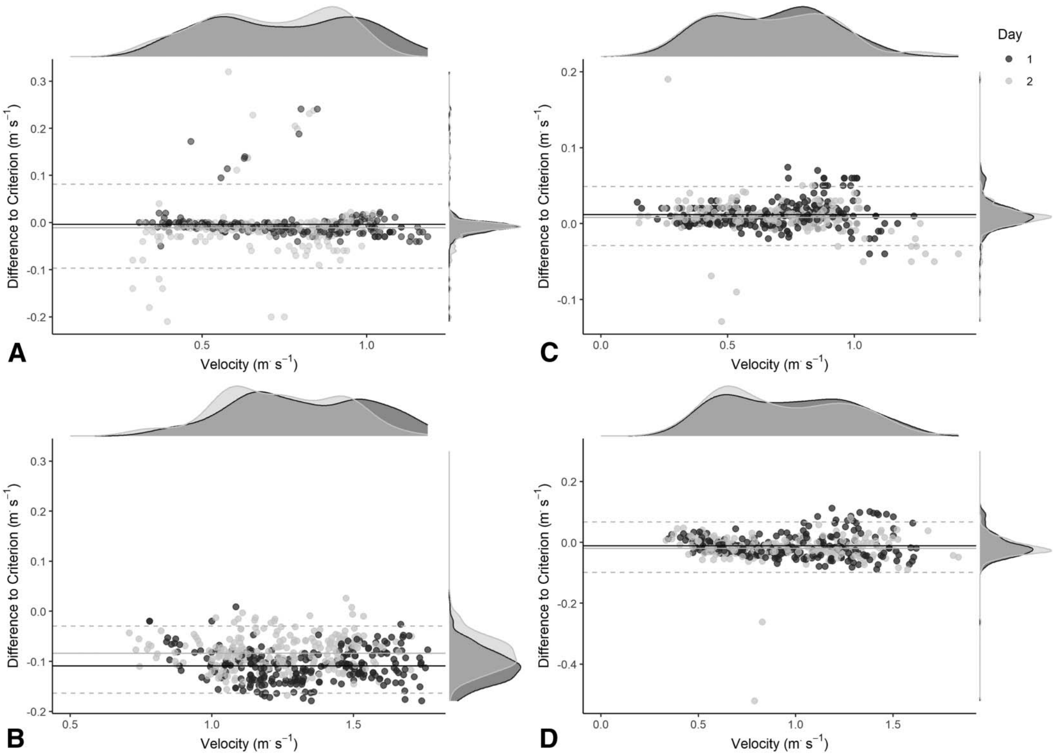

Figure 2. Bland-Altman plots for mean and peak velocity in the back squat (A and B) and bench press (C and D) showing average velocity and difference to the criterion measure. The solid horizontal line represents the average mean difference to criterion on day 1 (black line) and day 2 (grey line); dashed lines represent 95% confidence limits. Density plots are used to display the distribution of values on both testing days.

0.006); this difference (0.01 m·s^{-1}) is less than the MDC for peak velocity in the back squat across all intensities (Table 3). These differences are highlighted in Figure 2, with the mean difference for day 1 and day 2 indicated by the black and grey lines, respectively.

Between-Day Reliability

The results for reliability are shown in Table 3. These data account for both the technological and biological variation that occur when tasks are performed on separate days. The MDC can be used as a threshold for determining real changes in performance over time.

Discussion

The aims of this study were to (a) establish the criterion validity of mean and peak concentric velocity outputs from the Perch device during the free-weight barbell back squat and bench press at a range of intensities and (b) assess the between-day reliability accounting for technological and biological variability of the Perch device. Near perfect relationships in both mean and peak concentric

Table 2

Bar velocities and mean bias of the Perch compared with Vicon across all percentages of 1-repetition maximum (%1RM) for mean and peak velocities during the back squat and bench press exercises.*

	Mean velocity (m·s^{-1})			Peak velocity (m·s^{-1})		
%1RM	Perch	Vicon	Mean bias (95% CL)	Perch	Vicon	Mean bias (95% CL)
Back squat						
20%	0.99 ± 0.08	0.98 ± 0.11	0.01 (−0.01 to 0.02)	1.51 ± 0.14	1.59 ± 0.17	−0.08 (−0.09 to −0.07)
40%	0.90 ± 0.05	0.91 ± 0.06	−0.01 (−0.03 to 0.00)	1.41 ± 0.07	1.50 ± 0.08	−0.09 (−0.10 to −0.08)
60%	0.73 ± 0.05	0.73 ± 0.08	−0.01 (−0.02 to 0.01)	1.22 ± 0.06	1.33 ± 0.07	−0.11 (−0.12 to −0.10)
80%	0.53 ± 0.08	0.55 ± 0.06	−0.02 (−0.03 to −0.01)	1.04 ± 0.1	1.15 ± 0.12	−0.12 (−0.13 to −0.11)
90–100%	0.47 ± 0.10	0.48 ± 0.10	−0.01 (−0.02 to 0.01)	0.98 ± 0.11	1.07 ± 0.12	−0.10 (−0.11 to −0.09)
Bench press						
20%	0.98 ± 0.12	0.97 ± 0.13	0.01 (0.01 to 0.02)	1.42 ± 0.18	1.39 ± 0.13	−0.01 (−0.02 to 0.01)
40%	0.84 ± 0.08	0.83 ± 0.09	0.01 (0.01 to 0.02)	1.19 ± 0.15	1.21 ± 0.16	−0.02 (−0.03 to −0.01)
60%	0.68 ± 0.07	0.67 ± 0.07	0.01 (0.00 to 0.01)	0.93 ± 0.13	0.95 ± 0.13	−0.02 (−0.03 to −0.01)
80%	0.49 ± 0.09	0.48 ± 0.09	0.01 (0.01 to 0.02)	0.68 ± 0.11	0.69 ± 0.13	−0.02 (−0.03 to −0.01)
90–100%	0.38 ± 0.08	0.38 ± 0.09	0.01 (0.00 to 0.01)	0.56 ± 0.08	0.59 ± 0.11	−0.02 (−0.03 to −0.01)

*95% CL = 95% confidence limits.

Table 3

Test-retest reliability of the Perch device and minimum detectable change (MDC) to measure mean and peak velocity in the back squat and bench press exercises.*†

	Back squat		Bench press	
	SEM	**MDC**	***SEM***	**MDC**
20% 1RM				
Mean velocity	0.06	0.17	0.05	0.14
Peak velocity	0.06	0.15	0.08	0.21
40% 1RM				
Mean velocity	0.04	0.12	0.05	0.13
Peak velocity	0.04	0.12	0.08	0.23
60% 1RM				
Mean velocity	0.04	0.11	0.04	0.10
Peak velocity	0.05	0.13	0.06	0.17
80% 1RM				
Mean velocity	0.04	0.12	0.07	0.21
Peak velocity	0.06	0.16	0.07	0.19
90–100% 1RM				
Mean velocity	0.05	0.15	0.07	0.18
Peak velocity	0.05	0.14	0.06	0.17

*%1RM = percentage of one repetition maximum.

†These data reflect both biological and technological errors, and all values are in meters per second.

velocity were found between the Perch and criterion measure (Table 1), with relatively small bias. Additionally, bias was consistent across intensities within each exercise and variable (Table 2). To help establish reliability of the Perch device and account for biological variability, the between-day magnitudes of error for both the back squat and bench press were assessed, with no significant differences found in the mean and peak velocity for the bench press and the mean velocity of the back squat. However, a significant difference was found between days for peak velocity of the back squat. However, it should be noted that this difference was 0.01 $\text{m}\cdot\text{s}^{-1}$ and substantially less than the MDC for this exercise. Finally, the combined technological and biological error of the device has been provided to support practitioners (Table 3). This information can be used to guide programming decisions and to help detect real change in physical qualities when monitoring athletes. Overall, these findings indicate that the Perch is both valid and reliable for mean and peak velocity across all intensities. Practitioners and researchers may wish to use these results to guide training prescription and make informed decisions about changes in physical qualities.

Findings from this study suggest that when compared with the criterion, the Perch provides an accurate assessment of mean and peak velocity in the bench press and back squat across a range of velocities. For measures of mean velocity, this device is particularly accurate and demonstrates similar accuracy to linear position transducers (11,23). This accuracy during the back squat and bench press is important; it is advised that mean velocity is used to monitor performance because this variable has improved reliability when developing load-velocity profiles and has lower between-athlete variability in the velocity attained at 1RM (8,21). This suggests that the Perch can be used across a range of diverse monitoring and prescriptive methods including velocity loss thresholds (10,16,22) and 1RM estimation (5,7,9).

The between-day technological variability of the Perch, as measured by the error between the criterion and Perch across multiple days, is satisfactory (refer to Figure 2). This suggests that a substantial proportion of the difference in velocity outputs from the Perch between days is the result of the introduction of biological variance (e.g., small changes in technique, levels of effort, changes in readiness). This has been discussed in several reliability studies involving technology (3,4,19,20,31) with the need to distinguish between the error of the device and that introduced by human variation. Although a significant difference was observed between days for peak velocity in the back squat, this difference of 0.01 $\text{m}\cdot\text{s}^{-1}$ should be placed in context of the MDC. So that practitioners and researchers can better monitor changes across training cycles, the *SEM* and MDC of each intensity have been provided in Table 3. This information is useful when making decisions around altering training loads and when monitoring the physical qualities of athletes. Considering that these values are inclusive of biological variance, the low MDC values (23) indicate that the Perch appears to provide reproducible outcomes, which can support the provision of feedback and the monitoring of strength development across training mesocycles.

Although this study is the first to investigate the validity and reliability of the Perch device, there are several limitations that should be noted. First, the current study only investigated the barbell back squat and bench press. These movements were selected because they are commonly used during the validity and reliability assessment of velocity-based training equipment, and they are often implemented during resistance training programs. Although it is acknowledged that differing outcomes may occur with different exercises because of the similar pattern of accuracy reported between the 2 movements in the current study, it is unlikely that substantial differences would arise. Second, the current study only investigated the validity and reliability of mean and peak velocity. Although these velocity outcomes are commonly used to monitor and prescribe training (26), practitioners and researchers may also wish to investigate other kinetic and kinematic outputs.

In conclusion, this study has established the criterion validity and between-day reliability of mean and peak concentric velocity of the Perch device. Findings demonstrate that it can accurately monitor velocity of the barbell back squat and bench press, with mean concentric velocity demonstrating slightly greater accuracy than peak concentric velocity. Additionally, between-day technological error is extremely low, which indicates that the Perch can reliably be used to monitor changes in physical performance across time. When training, practitioners and researchers can use the MDC to infer changes in strength or fatigue, with these values provided across the entire load-velocity profile and helping account for both the technological and biological error associated with each of these exercises.

Practical Applications

Mean and peak concentric velocity are commonly used to prescribe resistance training and monitor adaptations in athletes. This is often performed with linear transducers, inertial measurement units, or optic lasers. However, this investigation provides evidence that the Perch device can monitor barbell velocity without any attachments to the bar or athlete. These findings can be used in several ways. First, because of the ability to accurately measure a range of velocities across a load-velocity profile, practitioners may wish to implement velocity loss thresholds to ensure that an adequate proximity to failure is reached during hypertrophic training or to mitigate fatigue when developing muscular strength or power. Second, because there are near perfect relationships between the Perch device and 3D motion capture, information from the Perch device can be provided as feedback to athletes to enhance motivation and competitiveness during training. Finally, using the MDCs provided, changes in physical qualities or fatigue can be monitored across time to support training practice.

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