Testing the validity and reliability of the RepOne Velocity sensor on Average concentric velocity in squat and bench press

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DISCLAIMER

This paper is originally written as a bachelor's thesis in Danish and has been translated to English. The Thesis was supervised by a member of staff, however the data collected and the result from this study is owned by, I, Marcus Thrane Leth, a sports science student at the university. No third-party company or similar was involved in the study design and conduct. There are no competing interests to declare.

Abstract

This study aimed to investigate the validity and test-retest reliability of the linear position transducer, RepOne, during submaximal squat and bench press. Eleven well-trained participants (10 males and 1 female) were recruited to perform a series of submaximal repetitions of squat and bench press while using the RepOne transducer to estimate speed of the lever. To assess validity, RepOne was compared to a gold standard for position, Vicon. The results showed a very strong correlation (R=0.997) between average concentric velocity (ACV) measured by Vicon and RepOne. The correlation between Vicon and RepOne closely aligns with the equivalence line, indicating no systematic bias. Validity was further supported by a t-test, which found no statistically significant difference between RepOne ACV and Vicon ACV (p = 0.151). The average difference between the measurement devices was 0.004 m/s (±0.006 m/s), which is considered negligible in a physical training context.

The reliability of RepOne was assessed in a test-retest design and found to be very good based on the biases observed in squat and bench press exercises, with values of +0.012 m/s and -0.001 m/s, respectively. These differences are considered negligible and attributed to human variance. The coefficient of variation (CV), which represents relative variation, for squat ACV was 2.8%, and for bench press ACV, it was 4.3%. The low CV values indicate a low relative variation in ACV. Overall, RepOne exhibited strong validity and reliability for measuring ACV in squat and bench press in well-trained participants.

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Introduction

Loading in strength training has for many years been a predefined load, often determined as a percentage of 1RM (repetition maximum). Training based on 1RM can be problematic as it relies on a previous performance (Helms et al., 2016). The previous performance can be irregular, either high or low, and may not accurately reflect the athlete's current ability to perform the lift (Helms et al., 2016). It should also be expected that the given athlete experiences progression through regular strength training, which will not be reflected in the loads until a new RM test is conducted.

Due to these issues, there has been an increase in autoregulated training programs (Hickmott et al., 2022). An autoregulated training program is one in which the training load is adjusted based on feedback. This adjustment is based on an athlete's acute and chronic changes in performance (Hickmott et al., 2022). Acute changes relate to an athlete's daily condition and readiness, which can be influenced by factors such as sleep, energy levels, and more. Chronic changes in performance, on the other hand, involve an athlete's strength gains and potential declines due to neural and muscular adaptations to training as well as injuries. Additionally, there is a broad consensus in the sports world that individualized training leads to better progress and lower injury risk (Greig et al., 2020). This individualization is largely achieved through autoregulation.

Autoregulation can be done subjectively and objectively (Hickmott et al., 2022). Subjective autoregulation can be performed, for example, using Rating of Perceived Exertion (RPE), which is a defined scale on which the athlete assesses their acute level of fatigue. In the study by Hackett et al. (2012), they examined 17 male bodybuilders' ability to assess their RPE in squats and bench presses. They used a modified RPE scale ranging from 0 to 10 and estimated repetitions until total exhaustion (Hackett et al., 2012). The study showed a strong correlation between estimated repetitions and actual repetitions to exhaustion, with $R^2 = 0{,}90$ for bench press and $R^2 = 0{,}87$ for squat. The study found a strong correlation, but their participants had an average of 8.2 years of training experience, suggesting that it requires considerable training experience to make a subjective assessment of fatigue (Garcin et al., 1998).

Objective autoregulation removes the athlete's feelings from the equation and relies on an objective measurement of a given lift, often a measurement of bar speed. The reason bar speed is often used is because of its inverse linear relationship with relative load (Greig et al., 2020). This means that the concentric speed of the bar during a given lift will decrease the closer it gets to 1RM. Speed is therefore heavily influenced by changes in performance, both acute and chronic. One of the reasons why velocity-based strength training has not been more popular is because it has traditionally been expensive and thus not accessible to the average strength-training individual.

Name	Type	Price	Age
RepOne	Linear Position Transducer (LPT)	~400 USD	2022-
TENDO	LPT	~1.700 USD	1993-
Vicon	3D Movement Capture	~71K-140K USD	1980-

Table 1 - Pricing overview for select velocity training devices.

In recent years, there has been an increase in consumer-accessible systems that can measure velocity during strength training (Thompson et al., 2020). With significantly lower prices than professional systems, it is much easier to adopt this training method, but it also raises questions about the validity and reliability of the measurements. This leads to the research question:

To investigate the validity and test-retest reliability of average concentric velocity (ACV) measured with the RepOne velocity sensor.

- Validity will be examined by comparing ACV measurements taken with RepOne to measurements made with advanced video analysis.
- Test-retest reliability will be assessed by examining the agreement between repeated measurements performed in two strength training exercises (squat and bench press).

Methods

Participants

The experiment was conducted with 11 strength-training students (>1 year of strength training experience), consisting of competitive powerlifters (n=7) and sports science students (n=4), including both males (n=10) and one female (n=1). The participants had an age (mean ± SD) of 24.9 ± 2.0 years, a height of 180.5 ± 9.8 cm, and a body weight of 86.6 ± 14.1 kg. Their estimated 1RM in squat and bench press was 143.8 ± 50.9 kg and 108.1 ± 41.8 kg, respectively. The participants had 6.4 ± 3.5 years of strength training experience and a self-assessed technique rating in bench press and squat of 4.5 ± 0.8 (on a scale of 1-6, poor to good).

The inclusion criterion for participation was to have an estimated 1RM (E1RM) of at least 1x body weight in squat and 0.5x body weight in bench press. Recruitment of participants was based on convenience, as the participants consisted of acquaintances from SDU Fitness and fellow students at SDU Sports and Health sciences.

Both genders were included in the experiment since the test was on the equipment's ability to measure velocity, and gender therefore should not influence the results. Furthermore, the linear relationship between ACV and relative load (percentage of 1RM) applies to both males and females (Mendonca et al., 2023). This means that there should be no difference in velocity measurements on barbells between men and women when considering relative load.

Before data collection, all participants signed a consent form in which the participants' rights in the project were explained.

Study design

The purpose of the study was to assess the validity and test-retest reliability of the barbell's average concentric velocity (ACV) measured with the RepOne velocity sensor. Validity was evaluated using a submaximal squat at 70% E1RM with 2 sets of 1 repetition with 3-minutes of rest. RepOne's measurements were compared to Vicon 3D motion capture, where reflective markers were placed on each end of the barbell.

Test-retest reliability was assessed in submaximal squat and bench press at 70% E1RM, with 3 minutes of rest between trials, consisting of 2 sets of 2 repetitions each. ACV was measured using RepOne. The tests were conducted based on a self-reported 1RM in the respective lift, and therefore, there was no need to test the 1RM to perform the experiment. Validity and reliability were tested on two separate days, with a minimum of 48 hours of rest between sessions.

Equipment

RepOne (RepOne Strength, New York, USA) is a device designed to measure barbell velocities during training. It is placed on the floor, and its wire is attached to the barbell. RepOne is a linear position transducer (LPT) and consists of an induction sensor, which operates by creating a magnetic field when the wire is pulled. The strength of the magnetic field created depends on how fast the wire moves, which the sensor measures, allowing it to calculate a velocity. This technology ensures that measurements of the barbell's velocity should be accurate regardless of the angle at which the wire is pulled, and RepOne can, therefore, measure movement in the full 3D space above the device, as stated by "RepOne's inductive sensor monitors motion in full 3D space . . ." (RepOne Strength, 2023). RepOne has a sampling frequency of 100 Hz, which means that the barbell's position is recorded 100 times per second. It can measure velocities ranging from 0.02 m/s to 10+ m/s, which includes squat and bench press, where at 70% 1RM, an ACV of approximately ~0.7 m/s and ~0.5 m/s is expected.

During the experiments, RepOne has magnets on the underside and is therefore placed on a small metal disc, to secure it to the ground. It is positioned laterally under the barbell in the starting position of the lift, with the wire attached using Velcro straps on the far-left side of the barbell. Data is transmitted from RepOne to the associated mobile app, RepOne Personal App (version 1.1.5), running on an Apple iPhone Xs (iOS 16.3.1). From there, it is exported as a CSV file for further data processing.

Exercise	Set	Rep	Weight	Metric	Set RPE	Tags	Workout Start Time	Rest Time	Avg Velocity (m/s)	Range of Motion (mm)	Peak Velocity (m/s)	Peak Velocity Location (%)	Duration of rep (sec)
sumo deadlift	1	1	70	kgs	< 5.5		3/2/2023, 16.49.58	00:00:00	0.56	530	1.19	331	0.95
sumo deadlift	1	2	70	kgs	< 5.5		3/2/2023, 16.49.58	00:00:00	0.81	522	2.16	259	0.643
sumo deadlift	1	3	70	kgs	< 5.5		3/2/2023, 16.49.58	00:00:00	0.72	530	1.38	318	0.736
sumo deadlift	2	1	90	kgs	< 5.5		3/2/2023, 16.49.58	03:26.5	0.45	539	1.2	323	1.2
sumo deadlift	2	2	90	kgs	< 5.5		3/2/2023, 16.49.58	03:26.5	0.62	535	1.23	311	0.865
sumo deadlift	2	3	90	kgs	< 5.5		3/2/2023, 16.49.58	03:26.5	0.61	535	1.2	339	0.882
sumo deadlift	3	1	110	kgs	< 5.5		3/2/2023, 16.49.58	02:16.8	0.48	518	1.04	337	1.074
sumo deadlift	3	2	110	kgs	< 5.5		3/2/2023, 16.49.58	02:16.8	0.45	517	1.11	340	1.137
sumo deadlift	3	3	110	kgs	< 5.5		3/2/2023, 16.49.58	02:16.8	0.57	523	1.15	316	0.918

Figure 1 - Example data from RepOne

The VICON system (VICON Motion Systems, Oxford, UK) was used as the reference measurement in the validity test. The system consists of 16 infrared cameras and 2 reference cameras, all operating at a frequency of 200 Hz. The system is controlled by VICON Nexus software (version 13.2, VICON Motion Systems, Oxford, UK). The cameras emit infrared light that reflects off reflective markers placed at each end of the barbell. The cameras are distributed throughout the measured space to triangulate the exact position of the markers with a measurement error of less than 0.2 mm^2. By knowing the position in space and the time between two positions, it is possible to calculate the speed at which the barbell is moving.

After a measurement, the data must undergo post-processing, during which the recording is reviewed for errors. Errors can include instances where a marker cannot be seen by the camera, resulting in the appearance of the barbell "jumping" in the recording. It can also occur when the barbell is mistaken for the reflective marker, creating noise in the recording. After quality control, a filter is applied to the recording to remove some of the noise. There will always be some level of noise in the recording generated by the cameras. The filter smoothes out the data, making it appear more continuous when viewed graphically.

After filtering, the data is exported as a CSV file and examined to identify the frames that correspond to the concentric phase of the lift. This is done by finding a start frame and an end frame. Both frames are identified by pinpointing all the frames where the velocity crosses zero, indicating a transition from the eccentric to the concentric movement of the barbell. Subsequently, a visual assessment is made to determine which of these frames represent the start and end of the concentric phase.

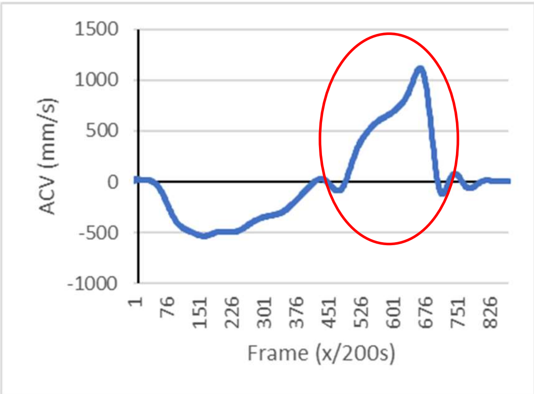

Figure 2 - Graph for ACV over time (y=ACV; x=Frame) Red marking shows the concentric phase

Once the range of frames for the concentric phase is identified, the next step is to calculate the average and maximum values to determine ACV and PCV respectively.

Measurements

Both devices measure and are compared based on the barbell's Average Concentric Velocity (ACV). The comparison is solely focused on concentric velocity because RepOne cannot measure the eccentric phase of the movement. The primary outcome of interest is ACV rather than Peak Concentric Velocity (PCV) because ACV is more valuable for training purposes due to its strong linear relationship with relative load and high inter-session reliability, as mentioned by Mendonca et al. (2023). Furthermore, it is not expected that there would be a difference in RepOne's ability to measure ACV and PCV since both are calculations based on its velocity measurements.

Exercise requirements

In the following section, we will explain the choice of squat and bench press, as well as provide descriptions and requirements for each movement.

The squat and bench press movements were chosen for the following reasons: 1) They are two of the most common compound exercises, making it easier to find participants who know their 1RM in these exercises. 2) Squat requires minimal equipment that could interfere with measurements in Vicon and has no risk of damaging the floor, as seen with exercises like deadlifts. 3) Both squat and bench press are integral to the competitive sport of powerlifting, which was a focus during the development of RepOne.

The squat consists of an eccentric and concentric phase, which are the downward and upward phases, respectively. Squat is a full-body exercise, meaning that most of the body's muscles are activated during the movement, with the primary movement occurring in the hip and knee joints. During the concentric phase, there is an extension of the knee and hip joints, while during the eccentric phase, there is flexion in these joints. The primary muscles involved in performing this movement are the Gluteus Maximus and Quadriceps. To be considered a valid squat for use in the experiment, the concentric phase must be executed smoothly, and the squat must reach a depth where the hip and knee joints are parallel.

In this study, the bench press consists of an eccentric, isometric, and concentric phase, which are the downward, pause on the chest, and upward phases, respectively. Bench press is also a full-body exercise with the primary movement occurring in the elbow and shoulder joints. During the concentric phase, there is an extension of the elbow joint and flexion of the shoulder joint, meaning that the primary muscles involved are the Triceps brachii, Pectoralis major, and Deltoideus. It is required that the participant has an isometric phase before the concentric phase to eliminate any momentum gained as the barbell bounces on the chest. Additionally, the bench press must be executed smoothly in the concentric phase, which means avoiding a strong extension at the end of the movement.

These specific requirements and descriptions ensure that the squat and bench press movements are standardized and can be accurately measured and compared between RepOne and the VICON system in the study.

Procedure

During the initial experiment, data on the participants were collected, and informed consent was obtained. This self-reported data included age, height, weight, training experience (in years), technical ability (rated on a scale of 1-6, with 6 being perfect and 1 being unable to perform the lift), and Estimated 1RM (E1RM) in squat and bench press.

Participants underwent a 5-minute standardized warm-up, followed by 10 minutes of specific warm-up exercises that they were accustomed to and a warm-up to the first test set at 70% of their E1RM. The choice of a 70% load was made to prevent the exercise from becoming ballistic, where the barbell loses contact with the body. This can occur with weights below 60-70%, especially when participants try to perform the concentric phase as quickly as possible. On the other hand, the load should not be so high that participants are unable to perform the lift, or they feel that participation in the project would interfere with their regular training and therefore choose not to participate.

Before each test set, participants were informed, in both reliability and validity tests, that they should perform the concentric phase of the movement at "full speed" and should avoid making a strong extension at the end of the concentric phase. This could potentially lead to measurement errors, especially in the squat, where a powerful hip extension at the end of the movement could distort the measurement. Visual assessment was made to determine whether participants executed the lifts acceptably. If the lift was not accepted, the participant was asked to repeat it.

In the validity test, after warm-up and information, the first squat consisted of one repetition at 70% of E1RM. The squat was performed with the participant's usual technique and equipment, following the previously mentioned range of motion requirements. After the first test set, the participant had a 3-minute break before performing the second test set. To limit data captured from Vicon, start and stop signals were given to indicate when the participant could start the squat and when they could rack the barbell. The information provided before each test set was standardized. After the session, data from both Vicon and RepOne were exported.

The reliability test was conducted on a different day and included the same warm-up and information as mentioned earlier. The test started with participants performing 2 sets of 2 repetitions at 70% of E1RM in bench press, following the previously mentioned range of motion requirements. After bench press, the participant had a 10-minute break before being tested on squat. The squat was performed with the same protocol as bench press, with the aforementioned requirements. Two repetitions were performed per set, but only the velocity from the fastest repetition in the set was compared. This choice was made to minimize the impact of variations in the participants' technique on the measurements. For example, if a participant did not position themselves properly initially and, as a result, could not generate maximum velocity, they could make minor adjustments and improve it on the second repetition.

There was a minimum of 3 minutes of rest between sets and a 10-minute break between exercises. A 3-minute rest is often sufficient for recovery to baseline at maximal loads (De Salles et al., 2009; Hernández Davó et al., 2016). In this experiment, testing was conducted at submaximal loads, so it was assumed that participants were fully recovered to perform the second set with a 3-minute break.

Statistical Analysis

To investigate the validity of RepOne, a correlation analysis was conducted. The purpose of the correlation analysis is to determine whether there is a linear relationship between ACV measured by Vicon and RepOne. The correlation analysis provides values ranging from -1 to 1, where 0 indicates no linear relationship, and (-)1 indicates a perfect linear relationship (Beyer et al., 2012). To assess the strength of correlation coefficients, Table 2 is used to interpret the individual values.

Table 2 - Interpretation table of correlation coefficients by Schober et al. (2018)

Absolute Magnitude of the Observed Correlation Coefficient	Interpretation
0.00–0.10	Negligible correlation
0.10–0.39	Weak correlation
0.40–0.69	Moderate correlation
0.70–0.89	Strong correlation
0.90–1.00	Very strong correlation

Since the correlation analysis only provides information about the relationship and not whether there is a difference between test results, a paired t-test is used as a supplementary analysis. The t-test examines whether there is a systematic change, in the same direction, between test results (Beyer et al., 2012). This is described by a p-value, which represents the probability that the difference occurred by chance under a given null hypothesis (Beyer et al., 2012). For example, $p<0.05$ means that there is less than a 5% chance that the difference occurred by chance, which is the significance level commonly used in sports research (Beyer et al., 2012).

The reliability of RepOne will be assessed using Bland-Altman plots with corresponding 95% limits of agreement. In these plots, the y-axis represents the difference between test sets 1 and 2, while the x-axis represents the average of test sets 1 and 2. The plot visually illustrates differences between measurements and allows for predicting, with 95% confidence, what the difference would be if a new experiment were conducted (Beyer et al., 2012). Additionally, the Coefficient of Variation (CV) will be calculated for both exercises. CV describes the relative variation in RepOne's measurements of ACV. It provides information about the precision and consistency of RepOne's measurements by quantifying the ratio of the standard deviation to the mean. This calculation helps assess the reliability of RepOne's measurements in terms of their relative variability.

Results

Validity

This study examines criterion validity using the Vicon system as gold standard and investigates the how the ACV measurements obtained with RepOne are consistent with those from Vicon.

The validity test was conducted on 8 participants, who are part of the previously described group of 11 participants mentioned in the participant section. Since the earlier description covered the entire group of participants, Table 3 describes the subgroup that participated in the validity test, segmented by gender.

label		Participants in the validity study		Total
		Female (n=1)	Male (n=7)	
Age (Years)	Mean (SD)	24.0 (NA)	24.4 (2.4)	24.4 (2.2)
Height (cm)	Mean (SD)	160.0 (NA)	184.7 (8.6)	181.6 (11.8)
Weight (kg)	Mean (SD)	53.0 (NA)	90.9 (10.2)	86.1 (16.4)
Training experience (Years)	Mean (SD)	4.0 (NA)	6.3 (3.3)	6.0 (3.2)
E1RM in Squat	Mean (SD)	60.0 (NA)	156.0 (41.7)	144.0 (51.4)
Technique in Bench and Squat (1-6)	Good (3)	0 (0%)	1 (14.29%)	1 (12.50%)
	Very good (4)	1 (100.00%)	2 (28.57%)	3 (37.50%)
	Advanced (5)	0 (0%)	4 (57.14%)	4 (50.00%)
	Perfect (6)	0 (0%)	0 (0%)	0 (0%)

Table 3 - Demography for the validity study

The study participants are relatively homogeneous in terms of age (24.4 ± 2.2 years), which aligns well with the fact that all participants recruited were students. All participants had a good level of experience (6.0 ± 3.2 years), with "advanced" being the most commonly reported technique level (50%). However, there is a reasonable amount of variation in 1RM squat (± 51.4 kg), which is related to the variation in body weight (± 16.4 kg).

The measurements of the barbell's ACV are described in Table 4. The slowest measured squat ACV was 0.472/0.478 m/s, while the fastest measured squat was 0.743/0.750 m/s.

	RepOne ACV (m/s)	Vicon ACV (m/s)
min/max	0.472 / 0.743	0.478 / 0.750
mean(SD)	0.636 (0.083)	0.640 (0.084)
n(NA)	8 (0)	8 (0)

Table 4 - Description of the minimum and maximum values, mean, standard deviation (SD), and sample size (n) for ACV measurements from the validity study, categorized by RepOne and Vicon.

To assess the validity of RepOne, we begin by examining the correlation between Vicon and RepOne's measurements of the barbell's ACV.

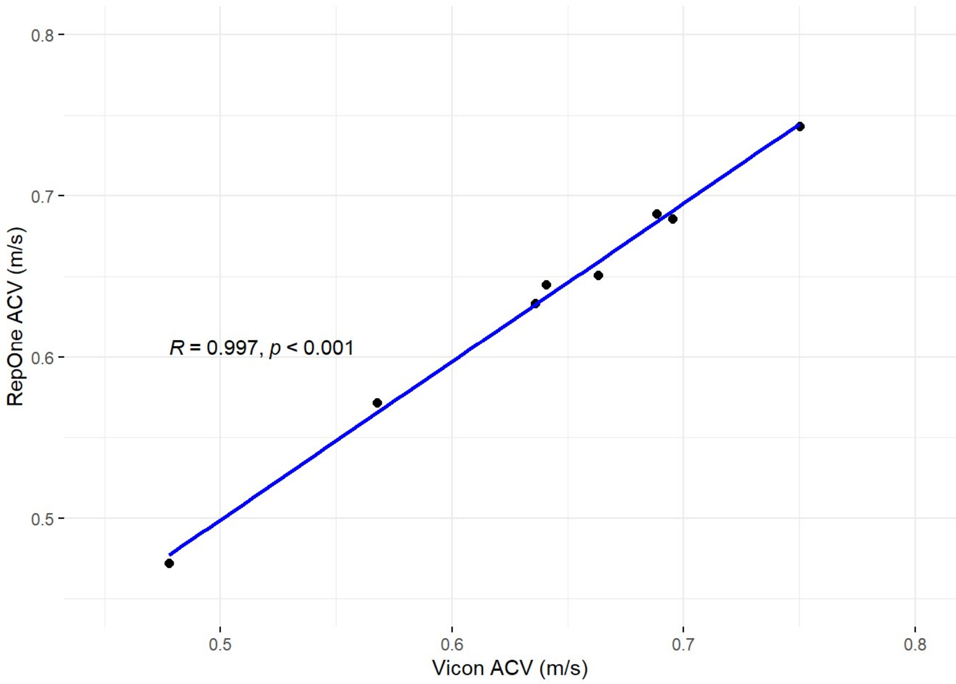

Figure 3 - Scatterplot (x=Vicon ACV; y=RepOne ACV), with best-fit line and associated Pearsons r and p-value

In the scatterplot in Figure 3, each point represents a participant's ACV from both Vicon and RepOne. The x-coordinate is the average ACV from Vicon across sets 1 and 2, while the y-coordinate is the average ACV from RepOne across sets 1 and 2. The best-fit line has been added to the plot, and it is evident that the individual points cluster closely around this line. This clustering is further supported by the strong correlation coefficient (Pearson's r), which is r=0.997, indicating a very strong correlation between the measurements from the two systems.

The associated p-value is less than 0.001, which means we can reject the null hypothesis. Based on the knowledge of the correlation, it is possible to conclude that RepOne is valid for assessing ACV in the inherent population. However, we do not yet know if there is a systematic bias (e.g., constant measurement error). To investigate this, we can plot an equivalence line on the scatterplot, which would have the equation y=x.

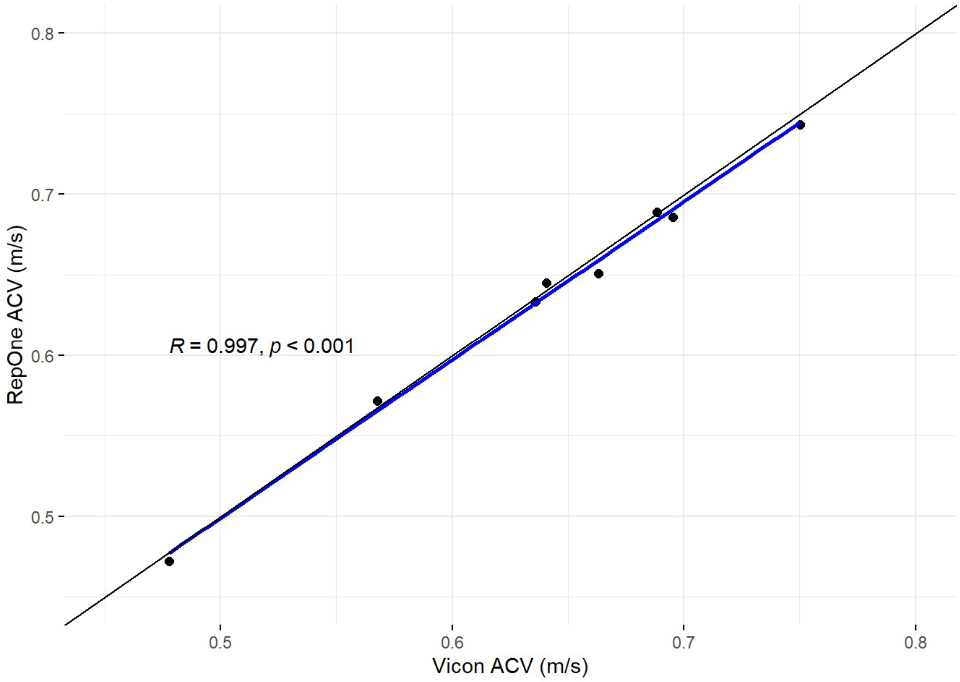

Figure 4 - Figure 3 with equivalence line: y=x

The added equivalence line (black) closely overlaps with the line that describes our data. This means that they are very close to being identical. Consequently, no systematic bias was seen between measurements systems.

To further support the validity of RepOne, a paired t-test was conducted to examine if the measurements are equivalent. For most statistical tests, it is a prerequisite that the data is normally distributed. This will be examined in a histogram where ACV measurements from RepOne and Vicon are plotted.

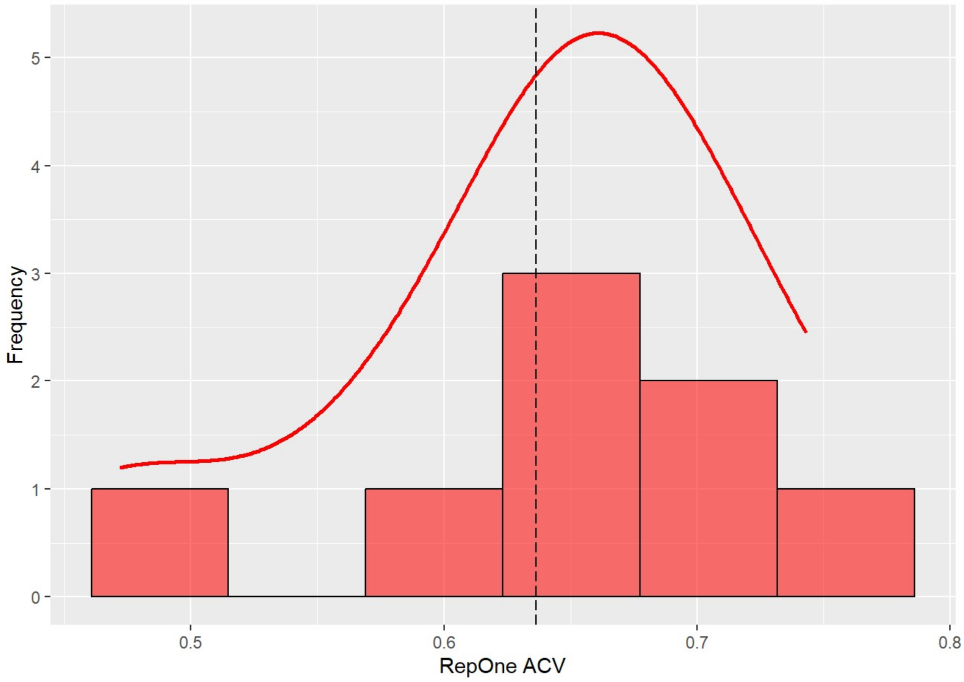

Figure 5 - Histogram with density curve for ACV-measurements with RepOne, and dashed line for mean.

The histogram and density curve describe the frequency of data at a given ACV. In a perfectly normal distribution, the curve would be more parabolic, without leaning to one side, and the bars would have a high central peak with bars decreasing in height on both sides. Figure 5 does not exhibit a perfectly normal distribution, but there is still a curve rising around the mean (dotted lines), which is why we consider this distribution to be approximately normal. This assumption is also based on the expectation that a larger sample size would result in a more clearly defined normal distribution.

When data is normally distributed, you can take the mean ± 1.96SD. This interval will contain 95% of all the data (95% CI). The straight line shown in Figure 3 consists of a slope and y-axis intercept. We calculate these values as well as the 95% confidence intervals for both.

	R	Slope (95% CI)	Intercept (95% CI)
ACV	0.997	0.983 (0.912, 1.054)	0.008 (-0.038, 0.053)

Table 5 - The formula for the best-fit line for ACV, along with the corresponding confidence intervals (95% CI).

The formula for a straight line is given as y = ax + b, so the formula for our data's correlation line is y = 0.983x + 0.008. If the line were perfect, it would be y = 1x + 0. The confidence interval for the slope (0.912, 1.054) contains 1, and the confidence interval for the y-intercept (-0.038, 0.053) contains 0. The fact that the confidence interval contains the equivalence line means that it is likely that RepOne and Vicon measure the same ACV.

By conducting a paired t-test between RepOne ACV and Vicon ACV, with the null hypothesis "the true average difference is equal to 0," we obtain a non-significant p-value of 0.151 (average difference = -0.00351 m/s, 95% C.I. [-0.00639, 0.00163]). Therefore, we cannot reject the null hypothesis since $p > 0.05$, which means that RepOne ACV and Vicon ACV are statistically equivalent.

RepOne's ACV validity in comparison to Vicon ACV in the squat demonstrates a very strong linear correlation ($R = 0.997$) and a corresponding linear model that includes the expected value (Table 5), indicating very strong criterion validity. This is further supported by a t-test indicating that there is no statistically significant difference between measurements from Vicon versus RepOne ($p = 0.151$). Additionally, the average difference is 0.004 m/s (±0.006 m/s), which means that the measurement difference is in the third decimal place. To provide context, the average squat ACV was 0.636 m/s. The difference is such a small fraction of squat ACV and, in most contexts, would be negligible.

Reliability

In this section, we will examine the test-retest reliability of RepOne by analyzing the collected data from the test-retest sessions for both squats and bench presses.

The reliability test was conducted with 10 participants, of whom 7 were also part of the validity test. Three participants were unable to perform squats due to injuries, resulting in a lower number of participants in the squat test. Table 6 provides a description of the participants, categorized by squat and bench press.

label		Participants in reliability study	
		Bench Press (n=10)	Squat (n=7)
Gender	Female	1 (10.00%)	1 (14.29%)
	Male	9 (90.00%)	6 (85.71%)
Age (Years)	Mean (SD)	25.4 (1.3)	25.3 (1.4)
Height (cm)	Mean (SD)	181.1 (10.6)	182.6 (12.5)
Weight (kg)	Mean (SD)	87.1 (15.5)	83.7 (17.4)
Training experience (Years)	Mean (SD)	6.5 (3.8)	5.9 (3.8)
E1RM in Squat	Mean (SD)	138.2 (52.8)	124.6 (52.5)
E1RM in Bench Press	Mean (SD)	106.9 (46.0)	92.0 (45.9)
Technique in Bench and Squat (1-6)	Good (3)	1 (10.00%)	1 (14.29%)
	Very good (4)	3 (30.00%)	3 (42.86%)
	Advanced (5)	5 (50.00%)	3 (42.86%)
	Perfect (6)	1 (10.00%)	0 (0%)

Table 6 - Demography for participants in the reliability study.

The participant group shares many of the same characteristics as described in Table 3, which is expected since the majority of participants from the validity test also participated in the reliability test (n=7). Between the bench press and squat groups, there are no significant differences except for the assessment of technique. In the bench press group, there is one participant who rates their technique as "perfect (6)," and there is also a dropout of 2 participants with "Advanced (5)" technique, resulting in a balanced distribution of 42.86% of participants with "Very good (4)" and "Advanced (5)" technique in the squat group.

The measurements of the bar's ACV in squats and bench press are described in Table 7.

	Squat Set 1 ACV (m/s)	Squat Set 2 ACV (m/s)	Bench Set 1 ACV (m/s)	Bench Set 2 ACV (m/s)
min / maks	0.519 / 0.826	0.512 / 0.824	0.433 / 0.673	0.400 / 0.687
Mean (SD)	0.668 (0.096)	0.680 (0.099)	0.492 (0.074)	0.491 (0.088)
n (NA)	7 (3)	7 (3)	10 (0)	10 (0)

Table 7 - Description of the minimum and maximum values, mean, standard deviation (SD), and sample size (n) for ACV measurements from the reliability trial, categorized by exercise and set.

To investigate any differences between the measurements in the test-retest, Bland-Altman plots for ACV in squat and bench press, along with their corresponding 95% limits of agreement (95% LOA), are now generated.

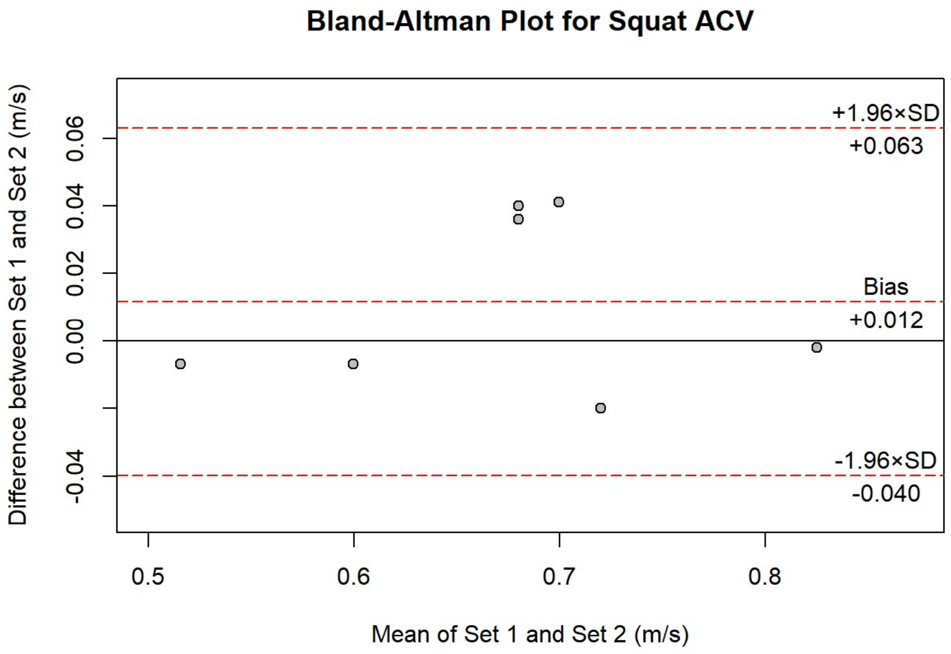

Figure 6 - Bland-Altman plot for Squat ACV. Each point represents an individual participant. The x-axis represents the average of ACV for sets 1 and 2; the y-axis represents the difference between set 1 and set 2 (set 2 - set 1). Additionally, there is a bias line, which is the average difference of all measurements, and lines for the 95% Limits of Agreement (LOA).

The squat ACV has a bias of +0.012 m/s, with a 95% LOA ranging from -0.04 m/s to +0.063 m/s. The bias indicates that, on average, participants were 0.012 m/s faster in their second set of squats, which is a negligible bias.

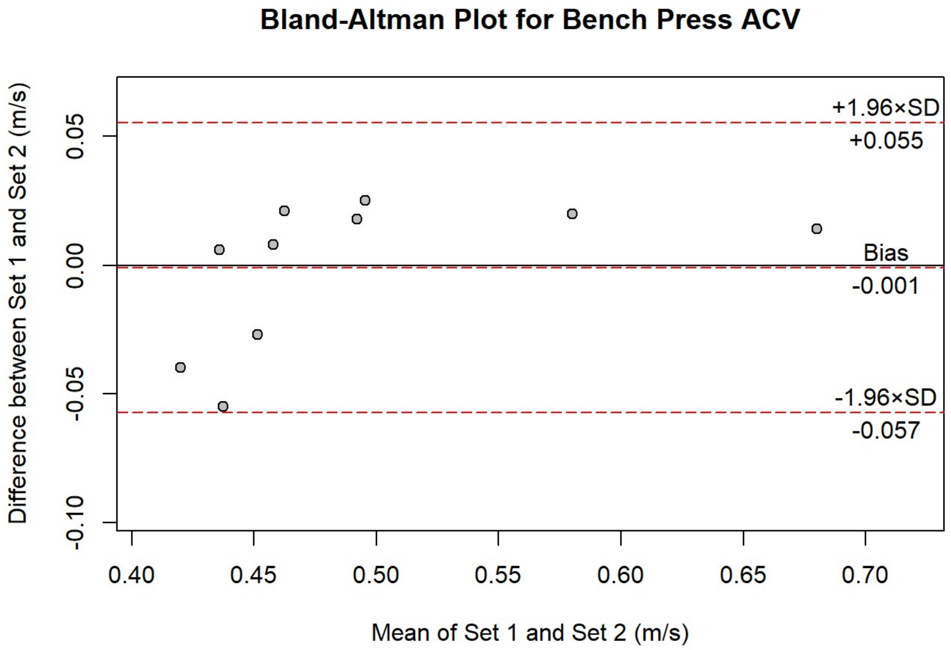

Figure 7 - Bland-Altman plot for Bench Press ACV. Each point represents an individual participant. The x-axis represents the average of ACV for sets 1 and 2; the y-axis represents the difference between set 1 and set 2 (set 2 - set 1). Additionally, there is a bias line, which is the average difference of all measurements, and lines for the 95% Limits of Agreement (LOA).

The bench press ACV has a bias of -0.001 m/s with a 95% LOA ranging from -0.057 m/s to +0.055 m/s. The bias indicates that, on average, participants were 0.001 m/s slower in their second set of bench presses, which is extremely close to having no bias (bias=0).

To assess the relative variation of ACV, a Coefficient of Variation (CV) is calculated, resulting in a CV of 2.8% for squat and 4.3% for bench press. These values indicate a low relative variation in ACV. Based on the low relative variation in ACV and the small biases in squat (+0.012 m/s) and bench press (-0.001 m/s), RepOne is considered to be highly reliable for test-retest measurements in both squat and bench press.

Validity and Reliability for peak concentric velocity

For each measurement of ACV, there is also a corresponding measurement of peak concentric velocity (PCV). However, the primary focus has been on ACV, as it has more practical applications in strength training, and there was an assumption that the validity and reliability would be similar for both ACV and PCV.

When conducting the validity analysis on squat PCV, measurements between 0.96 m/s and 1.366 m/s were obtained, which is expected to be higher than ACV (0.472-0.750 m/s). Next, a correlation analysis was performed, resulting in a correlation coefficient of r=0.998 (Figure 8). However, a significant difference is observed when the equivalence line (y=x) is added, with the entire correlation line lying below the equivalence line (Figure 8). This indicates that RepOne systematically measures a lower PCV than Vicon, which is supported by a paired t-test that is statistically significant (p=0.003), meaning that the average difference is not equal to 0.

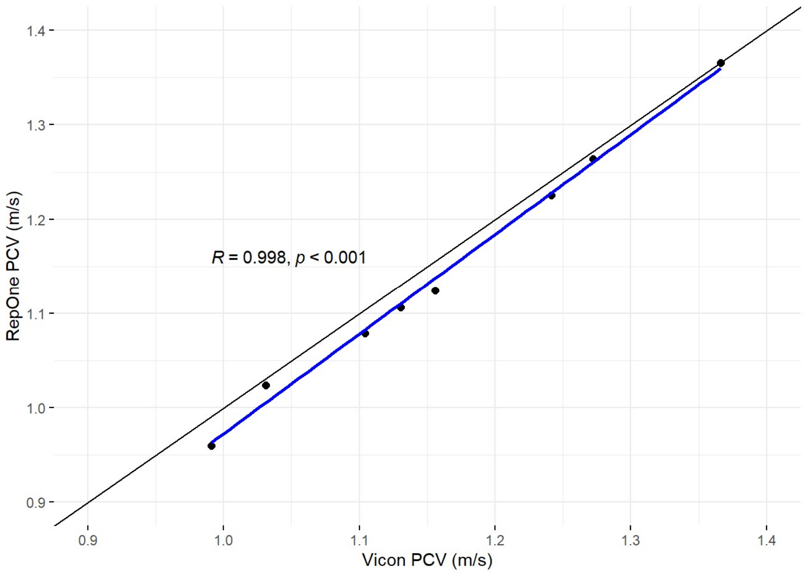

Figure 8 - Scatterplot (x=Vicon PCV; y=RepOne PCV), with best fit line and equivalence line, along with Pearson's r and p-value.

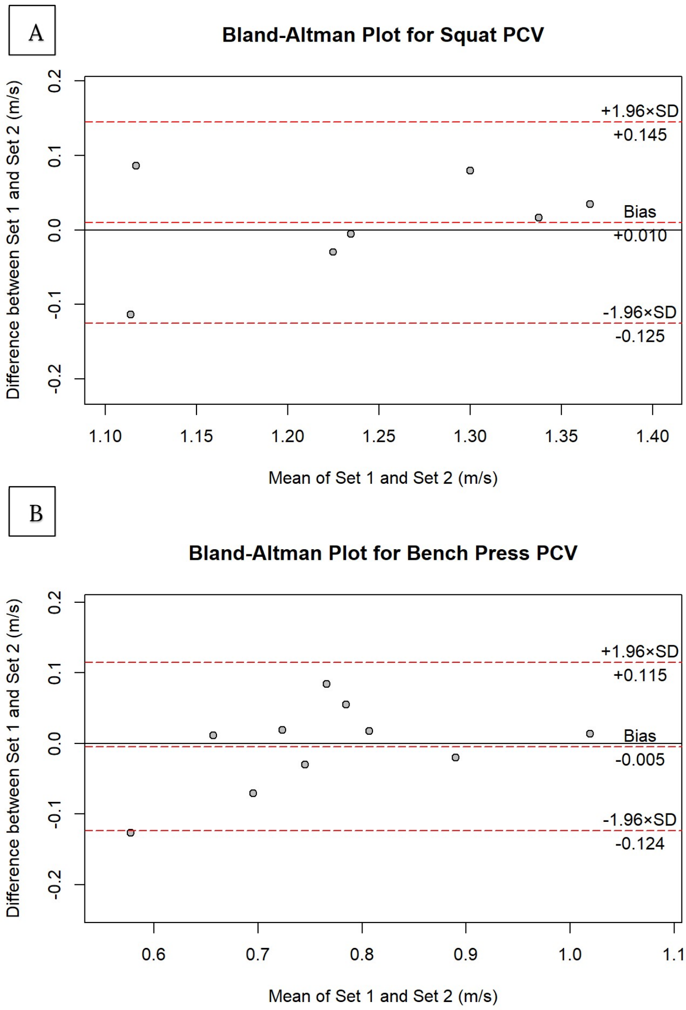

Figure 9 - Bland-Altman plot for Squat [A] and Bench Press [B] ACV. Each point represents an individual participant. The x-axis represents the average of ACV for set 1 and set 2; the y-axis represents the difference between set 1 and set 2 (set 2 - set 1). Additionally, there is a bias line, which is the average difference of all measurements, and lines for the 95% Limits of Agreement (LOA).

In the reliability trial, the average PCV in squat and bench press was 1.237 ± 0.093 m/s and 0.769 ± 0.113 m/s, respectively. By creating Bland-Altman plots for squat and bench press PCV (Figure 9), it's evident that the PCV biases are relatively close to those of the corresponding ACV measurements.

For squat (Figure 9A), the PCV bias is +0.010 m/s, while ACV bias is +0.012 m/s, and for bench press (Figure 9B), PCV bias is -0.005 m/s, and ACV bias is -0.001 m/s. However, their 95% limits of agreement (LOA) are somewhat higher (squat PCV [-0.13; +0.15] ACV [-0.04; +0.06]), which is due to the fact that PCV values are higher. To facilitate a better comparison of reliability between the two, the coefficient of variation (CV) is calculated, which is 3.9% for squat and 6.3% for bench press. These values are slightly higher than the CVs for ACV (Squat [2.8%]; Bench [4.3%]), but they are still sufficiently low to be considered reliable.

Discussion

A very strong correlation (r=0.997) was found in average concentric velocity (ACV) between Vicon and RepOne. The correlation between Vicon and RepOne is closely aligned with the equivalence line, indicating the absence of any systematic bias. Validity is supported by a t-test, which reveals no statistical difference between RepOne ACV and Vicon ACV (p = 0.151). The average difference between the measurement devices is 0.004 m/s (±0.006 m/s), which is interpreted as a negligible difference in training contexts.

The test-retest reliability of RepOne is assessed to be very good based on the bias in squat and bench press, which are +0.012 m/s and -0.001 m/s, respectively. These differences are considered negligible and are attributed to human variance. The relative variation described using the Coefficient of Variation (CV), for squat ACV is 2.8%, and for bench press ACV, it is 4.3%. These low CV values indicate low relative variation in ACV.

Based on the results for validity and test-retest reliability, RepOne is considered to have very strong validity and reliability for measuring ACV in squat and bench press.

In the study by Thompson et al. (2020), they tested the validity and reliability of six different devices (LPT n=1; Accelerometer n=5; Smartphone app n=1) for measuring ACV and PCV, one of which (Gymaware) is of the same type (linear position transducer (LPT)) as RepOne. The study used strength training exercises, squat and clean, with loads ranging from 40-100% of 1RM (Thompson et al., 2020). At 70% 1RM, they performed 2 repetitions with 3-5 minutes of rest between sets (Thompson et al., 2020). The study took place over four different days with intervals of 48-96 hours, where the first day consisted of 1RM testing, and the other three days were the experimental days (Thompson et al., 2020). For the reliability of squat at a load of 70%, they found an average difference of 0.03 m/s with a CV of 4.5%. RepOne achieved a lower average difference (0.012 m/s) and a lower CV (2.8%) in this study's experiments.

The validity of the devices in the study by Thompson et al. (2020) was assessed against the golden standard, Raptor 3D motion capture. They found an R^2 of 0.97 for squat at 70% 1RM, with the line equation $y = 1{,}073x - 0{,}060$. These results closely resemble the findings in this study, with an $R = 0{,}997$ ($R^2 = 0{,}994$) and the line equation $y = 0{,}983x + 0{,}008$. However, we have a significantly smaller confidence interval for the slope and intercept, [0.912; 1.054] and [-0.038; 0.053] respectively, whereas the Thompson et al. (2020) found confidence intervals of [0.917; 1.229] and [−0.172; 0.052], respectively. The study by Thompson et al. (2020) concludes that the mentioned LPT (Gymaware) is the most valid and reliable among the 6 devices they tested, with "practically perfect R^2 and minimal systematic bias".

Methodologically, there are a few differences between Thompson et al. (2020) and the experiments conducted in this study. These differences include: 1) The use of a 1RM test rather than self-reported 1RM. 2) Measurements for validity and reliability were taken across a range of 40-100% of 1RM, as opposed to solely at 70% 1RM. 3) Testing for inter-day test-retest reliability instead of intra-day test-retest reliability. In the study by Thompson et al. (2020), the participants were competitive weightlifters (n=10), with an average age of 25.0 ± 5.6 years, a body weight of 73.6 ± 13.9 kg, and a height of 169.6 ± 6.6 cm. The study did not specify the gender of the participants. The inclusion criterion for the study, in addition to being competitive weightlifters, was to have a squat of at least 1.5 times body weight. The participants in this study (n=11) are primarily powerlifters (n=7), with an additional n=4 sports science students. They have an average age of 24.9 ± 2.0 years, a body weight of 86.6 ± 14.1 kg, and a height of 180.5 ± 9.8 cm. Both populations are highly trained individuals in their mid-twenties, making them comparable. However, there are relatively large differences in height and body weight, with the participants in Thompson et al. (2020) being lighter and shorter. Additionally, there is a difference in the squat inclusion criterion, which means that the participants in the study have higher relative strength. Despite the inclusion criterion in our study being a squat of 1 times body weight, the average relative squat is 1.64 ± 0.49 times body weight, with 7 out of 11 participants meeting the inclusion criterion in Thompson et al. (2020). However, the study does not provide information about the participants' actual strength, which could potentially be much higher. The individual strength of each participant is not expected to significantly affect the results and can be seen more as an indicator of training experience and technique. Technique will have a significant impact on test-retest reliability if a participant has poor technique. However, all participants in both studies have a high level of technical proficiency, which should not significantly affect the comparability between the two studies.

In the study by Lorenzetti et al. (2017), the validity of three different Linear Position Transducers (LPTs) (T-force, Tendo, Gymaware) was examined against the golden standard, Vicon, for measuring average concentric velocity (ACV) during squats at 70% of 1RM, with 2 sets of 5 repetitions (Lorenzetti et al., 2017). They reported correlation coefficients for ACV as follows: T-force R = 0.970; Tendo R = 0.963; Gymaware R = 0.958, all of which they considered statistically significant correlations (Lorenzetti et al., 2017). The average difference (GF) between Vicon and the tested devices was as follows: T-force GF = 0.062 m/s; Tendo GF = 0.020 m/s; Gymaware GF = 0.046 m/s (Lorenzetti et al., 2017).

This study used the same golden standard (Vicon) and three similar devices (LPTs) to measure ACV during squats. However, there are protocol differences, such as performing 5 repetitions per set instead of 1 repetition, without specifying how the data were analyzed (maximum, mean, etc.). The population (n=9) in Lorenzetti et al. (2017) had a higher average age (30.9 ± 5.9 years), similar height (182 ± 6 cm), and similar body weight (92.0 ± 8.7 kg) compared to the population in this study. The participants in Lorenzetti et al. (2017) also had higher training experience (9.7 ± 5.5 years), which is associated with their older age. The population, exercise choice, tested apparatus (LPTs), and golden standard (Vicon) are highly comparable between the two studies. However, the protocol with 2 sets of 5 repetitions is significantly different from the protocol used in this study (2 sets of 1 repetition). Keeping this in mind, the results of this study show better correlation (R=0.997) and a lower average difference (0.012 m/s) compared to the study by Lorenzetti et al. (2017).

In the meta-study conducted by Weakley, Morrison, et al. (2021), they investigated studies that examined the reliability of velocity measurement devices. Comparable studies were selected, which included those investigating Average Concentric Velocity (ACV) reliability at 70% 1RM using a Linear Position Transducer (LPT). Among these, there are 3 similar studies for bench press ACV reliability (Boehringer & Whyte, 2019; Fernandes et al., 2021; Stock et al., 2011) and 3 similar studies for squat ACV reliability (Fernandes et al., 2021; Lorenzetti et al., 2017; Thompson et al., 2020).

For bench press ACV reliability, these studies reported the average difference and coefficient of variation (CV) as follows: (0.000 m/s; CV: 7.6%), (0.02 m/s; CV: 4.5%), (0.140 m/s; CV: 5.8%) (Boehringer & Whyte, 2019; Fernandes et al., 2021; Stock et al., 2011). The average difference for bench press ACV in this study (-0.001 m/s) is considerably lower than two of the studies and is similar to the last study. The CV in this study (4.3%) is lower than all three studies, though they are all relatively close, suggesting relatively similar reliability. For squat ACV, only one of the three studies is new, as the meta-study includes the studies by Lorenzetti et al. (2017) and Thompson et al. (2020). The new study reported an average difference of 0.038 m/s and a CV of 6.3% (Fernandes et al., 2021), which is the same as the other two studies, where RepOne achieved a lower average difference (0.012 m/s) and a lower CV (2.8%).

Weakley, Morrison, et al. (2021) also investigated other types of velocity measurement devices, categorizing them into accelerometers, Linear Position Transducers (LPTs), smartphone apps, and optical devices. Based on 44 independent studies, Weakley, Morrison, et al. (2021) concluded that LPTs are the most valid and reliable devices compared to accelerometers, smartphone apps, and optical devices. Among LPTs, Gymaware is the most extensively studied, with 9 independent studies, and it is found to be one of the most valid and reliable devices (Weakley, Morrison, et al., 2021).

RepOne has achieved better results for validity and reliability in this study compared to the respective devices used in comparable studies. All of these studies concluded that their respective devices are valid and reliable, which should also be applicable here, as there are no significant methodological differences between the studies. RepOne also falls into the category of the most valid and reliable velocity measurement devices in Weakley, Morrison, et al. (2021), and it performs better than Gymaware, which the study concluded to be one of the most valid and reliable devices. However, there is more research on the validity and reliability of Gymaware, which means that it cannot be concluded that RepOne is superior to Gymaware in measuring ACV in squat and bench press.

The study by Thompson et al. (2020) shows variation in reliability and validity depending on the load being tested. As mentioned earlier, the study involved lifts at 40-100% 1RM, with measurements taken at each 10% increment (40%, 50%, 60%, etc.). In this study, test-retest reliability for Gymaware varied from CV: 2.9% to 13.6%, with an average CV of 9.8% (Thompson et al., 2020). For all the devices tested in the study, there was an increase in CV with increasing load, indicating a decrease in reliability with higher loads (Thompson et al., 2020). This raises questions about whether this study can conclude reliability when measurements have only been taken at one load, and it is expected that there will be different results at different loads.

The drop in reliability with increasing load in Thompson et al. (2020) could potentially be attributed to the methodology used in their study. In their study, they performed 3 repetitions for low loads (≤60%), 2 repetitions for moderate loads (70-80%), and 1 repetition for high loads (≥90%). As the number of repetitions decreases, it can also be observed that reliability decreases, especially when only one repetition is performed at the respective load. The study does not specify whether calculations are performed for all lifts in the set, the maximum, or the average ACV. Therefore, there is a question as to whether the decreasing reliability could be due to a smaller amount of data. This criticism could be supported by Boehringer and Whyte (2019), who tested the reliability of bench press ACV with 2 repetitions in all sets, ranging from 30-80% 1RM, tested at every 10% increment. In this study, the average CV was 7.0% with a range between 3.7% and 11.0% (Boehringer & Whyte, 2019). However, it is still uncertain whether this is a methodological flaw, as the study by Boehringer and Whyte (2019) did not investigate reliability at 90-100% 1RM, which is where Thompson et al. (2020) found the highest relative variation and, therefore, the lowest reliability.

In practice, the small differences observed are unlikely to be significant in a training context. RepOne reports velocity with two decimal places during training, which means that differences in measurement at the third decimal place will be rounded and not reported during training. For example, if you're training based on velocity loss, the drop in ACV between repetitions will be so high that the small measurement difference will rarely result in variations in the number of repetitions in each set. If you're using ACV to track progress over time, the measurement difference will be less significant because you'll be following an upward trend where the measurement difference becomes a form of noise that doesn't prevent you from seeing the overall trend.

Conclusion

RepOne was found to have very strong reliability and validity in measuring average concentric velocity in squat and bench press. These results have been compared with similar studies investigating criterion validity and test-retest reliability of other velocity measurement devices. In these comparisons, better correlation coefficients were found in the validity correlation analysis, and lower or similar coefficients of variation were found for reliability, leading us to conclude that RepOne is valid for measuring ACV in the squat at 70% 1RM and is reliable for measuring ACV in both squat and bench press at 70% 1RM. Based on other studies that show variation in validity and reliability across a range of loads (40-100% 1RM), it appears relevant to investigate the validity and reliability at loads other than 70%, which is the focus of this study.

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