A comparative analysis of barbell velocity measurements across analog linear position transductors and computer vision smartphone camera-based motion tracking.

ABSTRACT

This study compared mean concentric velocity measured by Inform, a computer vision-based motion tracking system, with two widely used linear position transducers (LPT), GymAware and Vitruve, during the free weight barbell back squat and bench press across a range of loading conditions.

Two resistance trained participants completed sets at light, moderate and heavy intensities while all three systems recorded mean concentric velocity simultaneously in meters per second. Device outputs were summarised using set-average velocities and absolute differences between systems. Across both exercises, Inform demonstrated small mean differences relative to both linear devices, with discrepancies that were equal to or smaller than the differences observed between GymAware and Vitruve themselves.

Across both exercises, Inform produced velocity outputs that reflected the same load velocity relationships as those observed with the linear position transducers. Results indicated that Inform and GymAware shared consistent agreements throughout light, medium and heavy loads, with further findings highlighting Vitruve at times reported marginally lower mean velocities. Overall, Inform captured the expected decline in velocity within sets, in a manner comparable to both reference devices, indicating that camera-based tracking can provide comparable training metrics without requiring hardware attachment to the barbell.

INTRODUCTION

Velocity-based training has become a widely adopted approach within strength and conditioning, enabling practitioners to quantify training intensity, fatigue and neuromuscular performance through barbell velocity rather than relying solely on percentage-based loading prescriptions. The relationship between load and movement velocity is well established, with heavier loads producing slower mean concentric velocities and lighter loads producing faster velocities. Furthermore, the reduction in velocity within a set has been shown to reflect acute fatigue and can be used to autoregulate training volume and intensity.

Traditionally, barbell velocity has been measured using linear position transducers such as GymAware and Vitruve. These devices attach directly to the barbell via a tethered cable and calculate displacement over time to derive velocity. Linear position transducer systems are considered highly reliable and are widely used in both research and applied high-performance environments. However, they require dedicated hardware, physical attachment to the bar and a degree of set-up time, which may limit scalability across team settings or school-based environments.

Recent developments in computer vision and motion tracking have enabled camera-based systems to estimate barbell velocity without requiring physical attachment to the bar. These systems use video input and object-tracking algorithms to calculate displacement on a frame-by-frame basis, from which velocity can be derived through temporal analysis. If sufficiently accurate, camera-based tracking has the potential to reduce hardware costs, simplify set-up and improve accessibility to velocity-based training within schools, group training environments and larger squads.

There remains limited research directly comparing camera-based barbell tracking systems with established linear position transducers. Accordingly, the purpose of this study was to compare mean concentric velocity measurements obtained using Inform, a computer vision–based motion tracking system, with those recorded by two established linear position transducers, GymAware and Vitruve, during the free-weight barbell back squat and bench press across a range of loading conditions. It was hypothesised that the camera-based system would demonstrate comparable load–velocity relationships and within-set velocity decline patterns to the linear position transducers, with only small practical differences between devices.

METHOD

Participants

Two male athletes (Jack and Eddie) participated in this study. Both individuals had prior resistance training experience but differed in body composition, limb lengths, and overall anthropometric characteristics. This allowed for comparison across different movement patterns, tracking and bar path mechanics.

Equipment List

- Olympic squat rack
- Standard Olympic barbell
- Weight plates (varied loads)
- Vitruve linear position transducer (LPT)
- GymAware linear position transducer (LPT)
- Smartphone with the Inform application installed
- Adjustable phone mount
- iPads (for data visibility and recording reference)

Procedure

An iPhone with the Inform application was mounted to the squat rack using a fixed phone mount to ensure a consistent camera angle and stable recording position throughout all trials.

Both Vitruve and GymAware devices were attached to opposite sides of the barbell using their standard tether systems. This allowed simultaneous measurement of barbell displacement and velocity from both traditional linear position transducers.

To ensure accurate comparison, iPads displaying the LPT data were positioned within the camera's field of view. This enabled synchronized recording of:

- The athlete's movement
- Real-time velocity outputs from both LPT systems

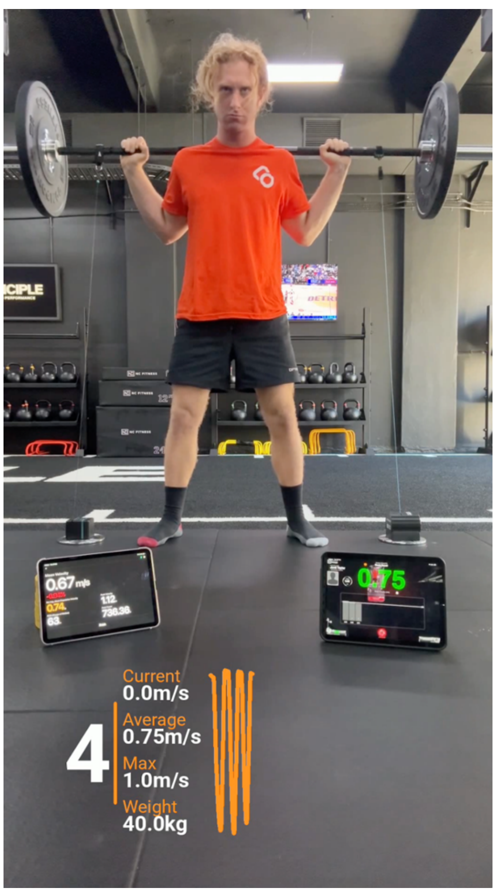
All lifts were performed within the same session environment to minimize variability in setup.

Before each exercise commenced, members of the testing group ensured that both linear position transducer cables were correctly aligned so that all systems recorded under consistent conditions and provided the most accurate comparison possible.

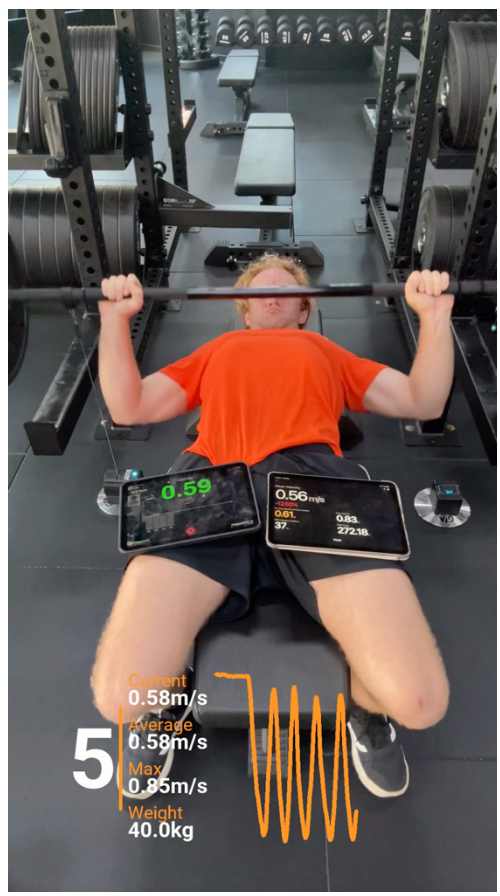
Repetition ranges and loads varied across trials, with sets ranging from three to over twenty repetitions at light, moderate and heavy intensities.

The image above illustrates the testing set-up for the barbell back squat.

The image above illustrates the testing set-up for the barbell bench press.



The image above shows the output generated by the Inform application for a back squat.



The image above shows the output generated by the Inform application for a bench press.

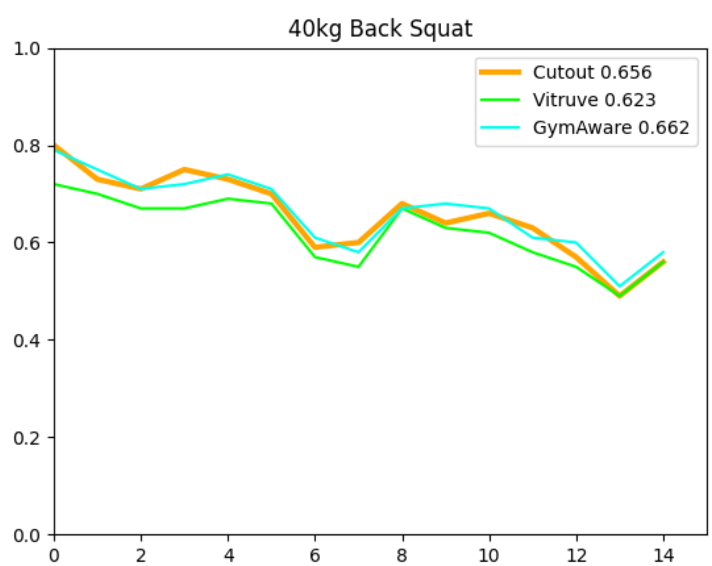
Data collection

Each set was categorised by exercise (bench press or back squat), total load and number of repetitions performed. All sets were logged in a central data table, with mean concentric velocity values recorded concurrently from Inform, GymAware and Vitruve for comparison (as seen below).

15 repetitions of an 40kg back squat.

Rep	Inform	Vitruve	GymAware
1	0.8	0.72	0.79
2	0.73	0.7	0.75
3	0.71	0.67	0.71
4	0.75	0.67	0.72
5	0.73	0.69	0.74
6	0.7	0.68	0.71
7	0.59	0.57	0.61
8	0.6	0.55	0.58
9	0.68	0.67	0.67
10	0.64	0.63	0.68
11	0.66	0.62	0.67
12	0.63	0.58	0.61
13	0.57	0.55	0.6
14	0.49	0.49	0.51
15	0.56	0.56	0.58
Average	**0.656** m/s	**0.623** m/s	**0.662** m/s

Above is an example of how data was recorded for each three of the velocity devices during a set on a rep per rep basis.



Above is a line chart demonstrating the similarities of the three devices

Statistical analysis

All statistical analyses were performed using repetition-level mean concentric velocity (MCV) data collected simultaneously from Inform, GymAware, and Vitruve during each lift. Descriptive statistics (mean ± standard deviation) were calculated for each device across all repetitions, loads, and exercises.

Each of the devices were compared with each other to calculate the mean difference in mean concentric velocity between systems. A positive value indicated that the first device reported higher velocities, whereas a negative value indicated lower reported velocities relative to the comparator device. The standard deviation (SD) of the differences was calculated to quantify random error between systems.

Comparison between devices was further evaluated using Bland Altman plot. For each comparison (Inform vs GymAware, Inform vs Vitruve, and GymAware vs Vitruve), the mean of the two devices was plotted against the difference between devices.

To further examine agreement between devices, residual distribution plots were generated for each pair of comparisons. (Inform vs GymAware, Inform vs Vitruve and GymAware vs Vitruve). Residuals were calculated as the difference in mean concentric velocity between the two systems for each repetition.

In all comparisons, measurements closer to zero indicate minimal bias between devices. Most outputs fell within ±0.05 m/s. Highlighting that all three systems are accurate to each other. The comparison between Inform and GymAware shared the highest agreeance overall.

Figure A and B demonstrate that the comparison between Inform and GymAware has the lowest mean residual distribution of the three device pairings during both bench press and back squat trials. The mean difference between Inform and GymAware for bench press was -0.011 m/s, indicating minimal bias and very close agreement. In contrast Inform and Vitruve was 0.031 m/s and GymAware and Vitruve showed the largest difference of 0.042.

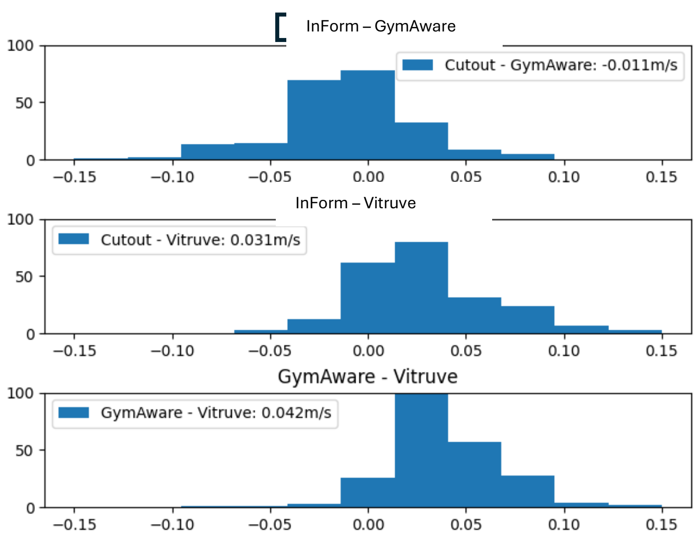


Figure A (Bench Press)

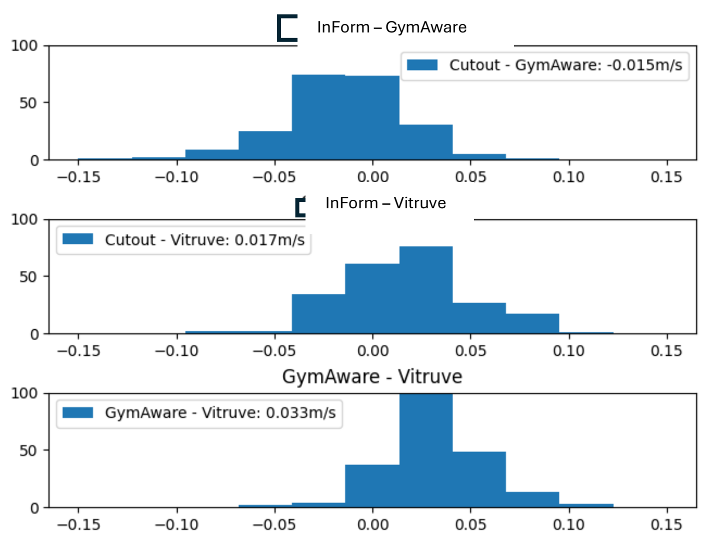


Figure B (Back Squat)

The Bland Altman plots illustrate comparisons between each velocity tracking system.

- The gold horizontal line represents zero difference, indicating that both devices recorded the same velocity for that repetition.
- The orange horizontal line represents the mean average for all three testing methods, providing a common variable for determining similarities.
- Each dot represents one repetition. The vertical position of the dot shows the difference between the two systems for that repetition.
- The highest velocity for Bench Press was 0.96m/s and the slowest was 0.11m/s.
- The highest velocity for Back Squat was 0.96m/s and the slowest was 0.31m/s.

Figure (c) represents a Bland Altman plot with a y-axis limit of ±0.5 points of difference for the Bench Press exercise.

- At this scale (±5 points of difference (POD)), the data points appear tightly clustered around zero, indicating small practical differences between systems.

Figure (d) represents a Bland Altman plot with a y-axis limit of ±0.2 POD for the Bench Press exercise.

- At this scale (±2 POD), the data points are slightly more scattered but still indicate minimal difference between the two devices. Strong accuracy is demonstrated between both GymAware and Vitruve with GymAware having a lower mean difference of -0.011 compared to Vitruve's mean difference of 0.031. This highlights the accuracy of Inform between the two devices. The upper and lower limits of acceptance (LOA) also indicate a small range of difference (0.059 and -0.080 for GymAware and a slightly higher 0.106 and -0.044 for Vitruve).

Figure e represents a Bland Altman plot with a y-axis limit of ±0.5 points of difference for the Back Squat exercise.

- At this scale (±5 POD), the data points appear tightly clustered around zero, indicating small practical differences between systems.

Figure f represents a Bland Altman plot with a y-axis limit of ±0.2 points of difference for the Back Squat exercise.

- At this scale (±2 POD), the data points are consistently spaced along the x-axis, indicating strong parity across a range of speeds. The mean difference for the three plots all range between -0.015 and 0.033 with similar upper and lower LOAs, also indicating a strong connection between devices.

Figure C

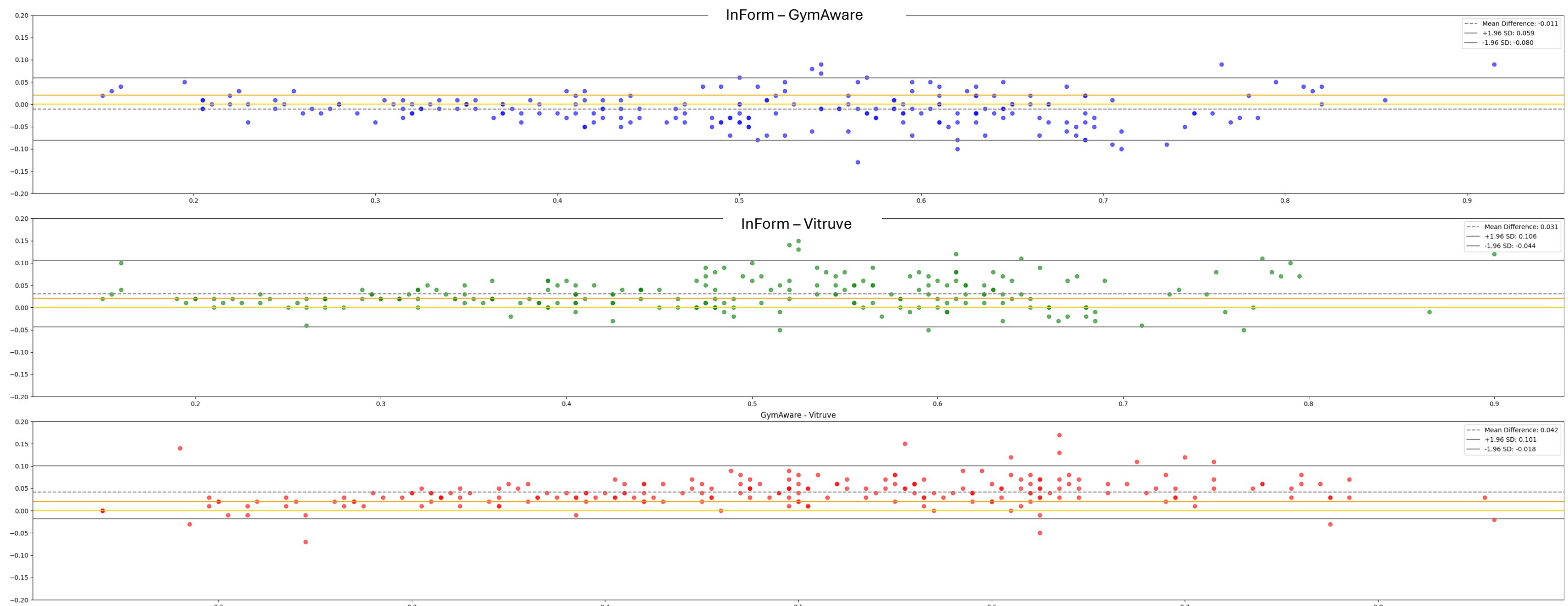


Figure D

Figure E

Figure F

RESULTS

Mean concentric velocity values recorded by Inform demonstrated close agreement with both linear position transducer systems across the free weight barbell bench press and back squat.

For the bench press, the mean absolute difference Inform and GymAware was 0.011 m/s indicating a strong agreement between the two systems. The mean absolute error (MAE) between the two datasets was 0.028m/s. The difference between Inform and Vitruve was slightly larger, averaging 0.031 m/s across all analysed repetitions with an MAE of 0.036m/s. The largest discrepancy existed between GymAware and Vitruve, which differed by a mean of 0.042 m/s across all repetitions and a MAE of 0.044. These findings demonstrate how the level of disagreement between Inform and the referenced devices was comparable to, and in some cases smaller than, the discrepancies between the two established linear transducers.

A similar pattern was observed for the back squat data. The mean difference between Inform and GymAware was 0.015 m/s with an MAE of 0.028, while the difference between Inform and Vitruve was 0.017m/s with an MAE of 0.029. The largest discrepancy again occurred between GymAware and Vitruve, differing by 0.033 m/s on average with an MAE of 0.035.

Across both exercises, Inform demonstrated agreement with the linear position transducers that was within the range of variability observed between GymAware and Vitruve themselves. Residual analyses showed that differences between systems were generally small and centred close to zero across the spectrum of observed velocities, with no clear systematic drift across loading conditions. Together, these results indicate that the computer vision–based system produced mean concentric velocity outputs that were most definitely comparable to those obtained from established linear position transducers during free-weight bench press and back squat.

CONCLUSION

This study examined the agreement between a computer vision-based barbell tracking system (Inform) and two established linear position transducers (GymAware and Vitruve) during the free-weight barbell bench press and back squat across a range of loading conditions.

Across both exercises, Inform demonstrated small mean differences relative to both linear devices, with discrepancies that were equal to or smaller than the differences observed between GymAware and Vitruve themselves. For the bench press, the smallest inter-device difference was observed between Inform and GymAware, while the largest discrepancy occurred between GymAware and Vitruve. A similar pattern was evident in the back squat, where Inform maintained close agreement with both linear transducers and the greatest divergence again occurred between the two hardware-based systems.

Bland–Altman and residual analyses further indicated that differences between devices were generally centred close to zero across the observed velocity spectrum, with no substantial evidence of systematic drift across light, moderate, and heavy loads. The magnitude of disagreement remained within a narrow practical range (predominantly within ±0.05 m/s).

Taken together, these findings support the hypothesis that a front on filming smartphone-based, computer vision tracking system can produce mean concentric velocity outputs that are practically comparable to established linear position transducers in applied strength and conditioning settings. While minor variability between devices is inevitable in free-weight movements, the magnitude and pattern of disagreement observed in this study indicate that Inform provides a valid and scalable alternative to tethered hardware systems for monitoring velocity-based training.