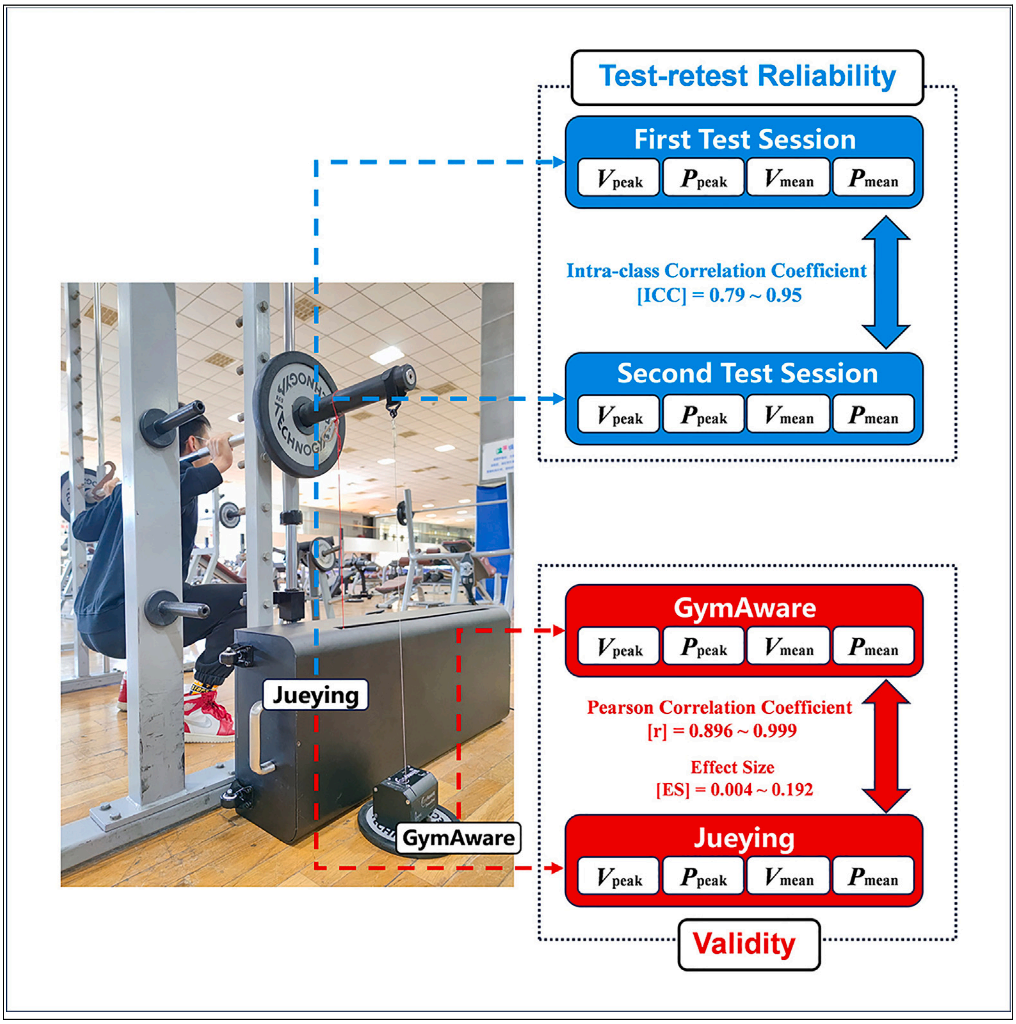
iScience

CellPress
OPEN ACCESS

Article

# Validity and test-retest reliability of a resistance training device for Smith machine back squat exercise




Hao-ran Qu, De-xing Qian, Shou-sheng Xu, Yan-fei Shen

qiandexing@bsu.edu.cn

## Highlights

Evaluate validity and reliability of an intelligent training device named Jueying

Jueying is valid when compared with GymAware and reliable in measuring speed and power

Jueying can provide athletes with valid and reliable data during squats

Qu et al., iScience *27*, 108582
January 19, 2024 
https://doi.org/10.1016/j.isci.2023.108582

Article

# Validity and test-retest reliability of a resistance training device for Smith machine back squat exercise

Hao-ran Qu,[1] De-xing Qian,[2,3,*] Shou-sheng Xu,[2] and Yan-fei Shen[2]

## SUMMARY

**This study evaluated the validity and test-retest reliability of a resistance training device Jueying (Beijing, China) for Smith machine back squat exercise. Twelve male participants completed two test sessions with an interval of one week. In each test session, participants completed 30%, 45%, 60%, and 75% of 1RM back squats on a Smith machine equipped with Jueying and a linear position transducer GymAware (Canberra, Australia), which measured the velocity and power during the movement simultaneously. Results showed that Jueying was both valid (Pearson correlation coefficient [r] = 0.896–0.999, effect size [ES] = 0.004–0.192) when compared with GymAware and consistent between two tests in terms of reliability (intraclass correlation coefficient [ICC] = 0.79–0.95) to assess speed and power within all exercises. The device could be applied to provide athletes and coaches with effective and reliable data in actual application.**

## INTRODUCTION

Strength and power are very important for sports performance, and the accurate measurement and evaluation of these qualities during sports training is the fundamental step toward their improvement.[1] At present, resistance training is one of the main forms of exercise to develop strength and power, which causes the muscles to contract against any external resistance imposed on the body by the outside world, such as dumbbells, barbells, and resistance bands.[2] This method is simple and effective, but it is difficult to monitor the parameters during exercise in real time, and it is not convenient to evaluate the exercise state. Determining the optimal range of training loads can maximize muscle strength per unit time and reduce the risk of overtraining and/or overusing injuries, which is very important for the efficiency and safety of training.[3] Although there are different methods to determine the training load, the most common method, traditionally called percentage-based training (PBT), specifies the relative load to be used in training from a previously established one repetition maximum (1RM). As the maximum strength is dynamic, it will fluctuate continuously due to fatigue accumulation or compensation within different periods of the training cycle, so the method of using 1RM to specify relative load is questioned. To overcome such limitations and complement PBT, scholars proposed the velocity-based training method (VBT) and verified the feasibility of using the mean velocity (MV) of the movement to monitor the load by applying a commercial cable velocity measuring device (T-FORCE) to the conventional strength training.[4] It is proved that the velocity is closely related to the relative load of specific exercise,[5] and there is a strong relationship between the velocity loss, the ratio of maximum repetitions, and metabolic markers of neuromuscular fatigue.[6] These studies claimed that the change of movement velocity may be a more objective method to quantify the intensity of resistance training.

VBT is a new training method to design, monitor, and adjust the strength training load by using the strong correlation between movement velocity and %1RM, repetitions, and fatigue.[7] Generally, the evaluation of power adopts two indices: mean power and peak power. Average power refers to the average value of power output from the beginning to the end of the movement, which reflects the average output level of the whole movement. Peak power refers to the maximum value of power output, which is the best index for evaluating explosive power.[8] With the continuous development of technology, measuring devices such as cable velocity measurement, infrared systems, and accelerometers are widely used in sports practice and research.[9] Some researchers have evaluated the reliability and validity of most devices such as Tendo and Push Band and found that these devices are effective and reliable.[10,11] These commercial linear positional transducers (LPT) are composed of cables, spools, and rotation sensors or encoders.[12] When in use, cables are connected with athletes or weightlifting rods. When cables move with moving objects, spools and sensors rotate, and sensors generate electrical signals related to the linear extension distance of the cables. Data such as time and displacement can be collected in real time through computer analysis and calculation. These data, together with the athlete's weight and load, are then used to calculate more variables, such as velocity, acceleration, force, and power. GymAware is a commercial LPT, which has been used in a series of studies to evaluate velocity[13] and power.[14] At present, many studies have proved the reliability and validity of the devices for monitoring the power and velocity of resistance training.[15–17]

[1]Beijing Sport University, School of Sport Science, Beijing 100084, China
[2]Beijing Sport University, School of Sport Engineering, Beijing 100084, China
[3]Lead contact
*Correspondence: qiandexing@bsu.edu.cn
https://doi.org/10.1016/j.isci.2023.108582


**Figure 1. Jueying and GymAware for experiments**
Jueying (A, left) and GymAware (B, right) attached to Smith machine.

Jueying (Beijing, China), an intelligent device for resistance training, is a kind of device that takes the motor torque as the source of resistance and connects with the athlete through the high-strength cable, enabling the athlete to train by overcoming the resistance transmitted by the cable. The device can accurately and quickly adjust the training load through the operating system and can monitor the velocity, power, and other indices simultaneously in real-time through the data obtained from the built-in encoder in the servo motor using a software algorithm. Accurate recording of training data can provide a reference for the adjustment of training arrangements, to realize more efficient training and effectively improve the athlete's performance. The device can be used in situations where constant resistance should be provided for a long distance, such as sprint and swimming, and can also be used in resistance training with weight training equipment such as the Smith machine to monitor the velocity and power. To verify that the device provides trustworthy measurements of the relevant parameters during the resistance training, the purpose of this study is to assess the validity and test-retest reliability of Jueying versus a linear positional transducer system (Figure 1) when measuring velocity and power-related data during Smith machine back squat exercise of different load conditions and to provide an accuracy guarantee for the subsequent application of the device.

Jueying is an intelligent resistance training device developed by Beijing Sport University, which can provide variable resistance while accurately monitoring power, speed, and other indicators during exercise. The device uses high-density cable to connect the athlete to the device and computer software to control the torque of the servo motor to adjust the resistance provided to the athlete. At the same time, using high-precision built-in sensors to monitor the velocity of cable, filtering, and smoothing algorithms to calculate the speed and power of the athletes. Compared with traditional training devices, Jueying can conveniently adjust the training load, monitor movement data at the same time, improve the efficiency of training, and provide great help for the coaches and athletes.

Training condition evaluation during resistance training is an important part of athletes' monitoring project, so it is necessary to ensure that the measurement tools used by athletes and strength and conditioning practitioners are valid and reliable. The purpose of this experiment was to verify the accuracy of the monitoring of the relevant indicators of resistance training, so as to provide an accurate monitoring means. This experiment compared the data of GymAware, a verified test device, with that of a new intelligent resistance training device, in order to show that the monitoring function of Jueying can be applied to actual training. Jueying can provide training and monitoring functions at the same time. This new device is conducive to improving the efficiency of training. This research is needed to verify the accuracy of the testing function of this equipment.

## RESULTS

The average (mean $\pm$ SD), mean difference, *r*, and effect size (ES) of peak velocity ($V_{peak}$), peak power ($P_{peak}$), mean velocity ($V_{mean}$), and mean power ($P_{mean}$) of the two devices under different load conditions are shown in Table 1. For all the measured variables, Pearson's *r* ranged from 0.896 to 0.999 and showed a very high correlation between the two devices. Meanwhile, the ES ranged from 0.004 to 0.192, equivalent to a trivial difference.

The linear regression analysis revealed fixed biases for $V_{peak}$ and $P_{mean}$ and proportional biases for all the variables (Table 2). The mean difference between the two devices was very small, and the $R^2$ ranged from 0.975 to 0.995, meaning the data from the Jueying device explained a very high proportion of the variance of that from GymAware.

Figures 2, 3, 4, and 5 displayed the Bland-Altman plots for $V_{peak}$, $P_{peak}$, $V_{mean}$, and $P_{mean}$ of the two devices under different load conditions. The 95% confidence interval (CI) represented the magnitudes of random errors in relation to the systematic difference. Within all plots, there was only one or no value outside the agreement limit when the Smith machine back squat was performed under different loads.

The test-retest reliability parameters of Jueying are shown in Table 3. For $V_{peak}$, $P_{peak}$, $V_{mean}$, and $P_{mean}$, ICC ranged 0.79–0.95, 0.84–0.95, 0.82–0.89, and 0.82–0.92, respectively, showing good to excellent consistency.

Table 1. Validity assessment of individual loads for Jueying

| | | Average (mean ± SD) | | | | |
|---|---|---|---|---|---|---|
| Variable | Load | Jueying | GymAware | Mean difference | $r$ | ES |
| $V_{peak}$ (m/s) | 30% 1RM | 0.793 ± 0.215 | 0.791 ± 0.209 | −0.002 | 0.999 | 0.004 |
| | 45% 1RM | 0.772 ± 0.225 | 0.765 ± 0.215 | −0.006 | 0.998 | 0.014 |
| | 60% 1RM | 0.802 ± 0.164 | 0.792 ± 0.150 | −0.010 | 0.991 | 0.033 |
| | 75% 1RM | 0.756 ± 0.147 | 0.744 ± 0.136 | −0.012 | 0.989 | 0.042 |
| $P_{peak}$ (w) | 30% 1RM | 894.9 ± 306.2 | 887.7 ± 291.8 | −7.212 | 0.993 | 0.012 |
| | 45% 1RM | 993.9 ± 351.5 | 982.8 ± 344.1 | −11.061 | 0.996 | 0.016 |
| | 60% 1RM | 1199.1 ± 344.4 | 1167.9 ± 323.9 | −31.185 | 0.990 | 0.047 |
| | 75% 1RM | 1258.9 ± 357.9 | 1225.9 ± 332.1 | −32.948 | 0.976 | 0.048 |
| $V_{mean}$ (m/s) | 30% 1RM | 0.507 ± 0.098 | 0.516 ± 0.102 | 0.009 | 0.986 | 0.045 |
| | 45% 1RM | 0.477 ± 0.095 | 0.496 ± 0.105 | 0.018 | 0.974 | 0.090 |
| | 60% 1RM | 0.454 ± 0.052 | 0.475 ± 0.057 | 0.021 | 0.896 | 0.189 |
| | 75% 1RM | 0.398 ± 0.053 | 0.418 ± 0.058 | 0.019 | 0.925 | 0.174 |
| $P_{mean}$ (w) | 30% 1RM | 521.1 ± 115.9 | 533.5 ± 124.1 | 12.383 | 0.986 | 0.051 |
| | 45% 1RM | 562.9 ± 125.9 | 587.5 ± 140.9 | 24.588 | 0.973 | 0.092 |
| | 60% 1RM | 605.6 ± 94.2 | 637.8 ± 107.7 | 32.132 | 0.927 | 0.157 |
| | 75% 1RM | 586.6 ± 76.3 | 618.9 ± 88.5 | 32.265 | 0.911 | 0.192 |

## DISCUSSION

The present study analyzed the validity and the test–retest reliability of a resistance training device in comparison to a linear positional transducer system for measuring velocity and power metrics during the execution of Smith machine back squats under different loads by young, physically active adults with strength training experience. Jueying was both valid (Pearson correlation coefficient [r] = 0.896–0.999, effect size [ES] = 0.004–0.192) when compared with GymAware and consistent between two tests in terms of reliability (intraclass correlation coefficient [ICC] = 0.79–0.95) to assess speed and power within all exercises. Results show that Jueying can validly and reliably evaluate the velocity and power during Smith machine back squat training.

Training condition evaluation during resistance training is an important part of athletes' monitoring project, so it is necessary to ensure that the measurement tools used by athletes and strength and conditioning practitioners are valid and reliable. The change of movement velocity may be a more objective method to quantify the intensity of resistance training. Average power reflects the average output level of the whole movement, and peak power is the best index for evaluating explosive power. Jueying has high validity and good to excellent reliability in evaluating the velocity and power of the Smith machine back squat. Therefore, athletes and coaches can use Jueying to obtain effective and reliable data on smith machine back squats. Accurate recording of training data can provide a reference for the adjustment of training arrangements, so as to realize more efficient training and effectively improve the athlete's performance.

In this study, the first purpose was to evaluate the validity of Jueying, which was achieved through the comparative analysis of data obtained from Jueying and GymAware. The results showed that there was little difference between the measured variables ($V_{peak}$, $P_{peak}$, $V_{mean}$, and $P_{mean}$) for the two devices under different load conditions. Data obtained from them have extremely high correlations, and the ES of all variables was less than 0.2, which showed that the difference between the two sets of data was small. There were fixed biases in the overall data of all variables except $P_{peak}$ and $V_{mean}$, and proportional biases in the overall data of all variables, which might be caused by different sensors of the two devices. Due to the different sizes of the two devices, the accuracy of their sensors will also be different. Therefore, different sensitivity of the capture system (sampling frequency) may cause certain biases. In order to solve this problem, it is necessary to use other means such as a dynamometer or high-speed camera to evaluate Jueying. To sum up, data obtained from Jueying and GymAware had high correlations, small differences, and good consistency, which means that Jueying has high validity.

Table 2. Linear regression of data obtained from Jueying and GymAware across all loads

| Variable | Mean difference | $a$ | 95% CI for $a$ | $b$ | 95% CI for $b$ | $R^2$ | Fixed bias | Proportional bias |
|---|---|---|---|---|---|---|---|---|
| $V_{peak}$ (m/s) | 0.008 ± 0.005 | −0.029 | −0.047 to −0.011 | 1.047 | 1.024–1.070 | 0.995 | Yes | Yes |
| $P_{peak}$ (w) | 20.6 ± 13.4 | −32.908 | −74.971 to 9.155 | 1.05 | 1.013–1.088 | 0.986 | No | Yes |
| $V_{mean}$ (m/s) | −0.017 ± 0.005 | 0.009 | −0.013 to 0.031 | 0.945 | 0.900–0.991 | 0.975 | No | Yes |
| $P_{mean}$ (w) | −25.3 ± 9.4 | 46.951 | 25.085–68.817 | 0.878 | 0.842–0.914 | 0.981 | Yes | Yes |

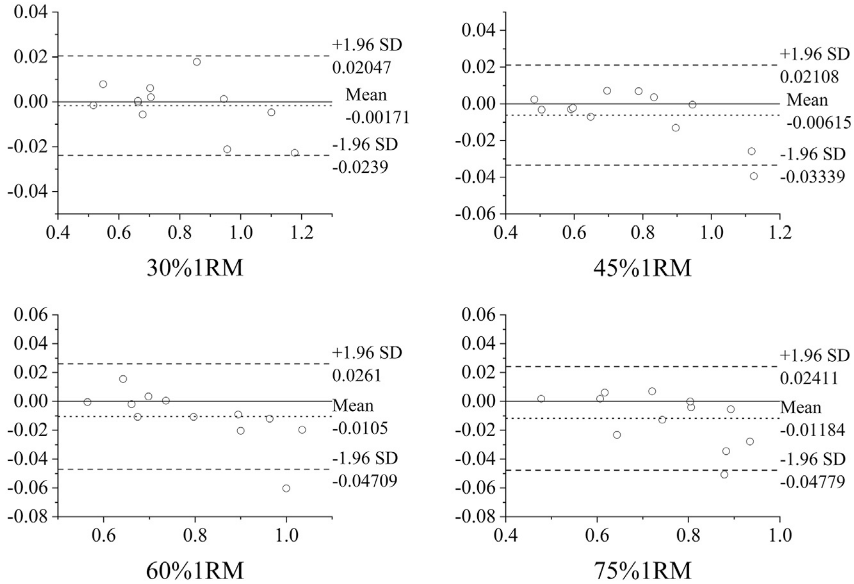



**Figure 2. Bland-Altman plots of $V_{peak}$ of Jueying and GymAware at 30%, 45%, 60%, and 75% 1RM**

In this study, another purpose was to evaluate the test-retest reliability of Jueying, which was realized through the comparative analysis of two tests. The variables calculated from the Jueying are all derived from the collected position data. The sensors of Jueying have good accuracy, besides. To reduce the error of the data, care should be taken to minimize noise in the original data and ensure suitable smoothing methods are used. Jueying optimizes the data processing process to reduce errors. Results show that Jueying has good to excellent reliability in evaluating the velocity and power of the Smith machine back squat. In addition, under low, medium, and high loads, the reliability of squat velocity and power seemed to be the same.

Jueying consistently overestimated mean velocity according to the Bland-Altman plots. The reason could be the difference between the sampling rate of the two devices. The values of average speed and average power depend on the sampling rate of test equipment. The sampling rate of Jueying is higher than that of Gymaware, so the average speed and average power obtained by Jueying are higher than that of GymAware. In actual training and testing, the higher sampling rate increases the amount of raw data processed by the data device, and more accurate test data can be obtained.

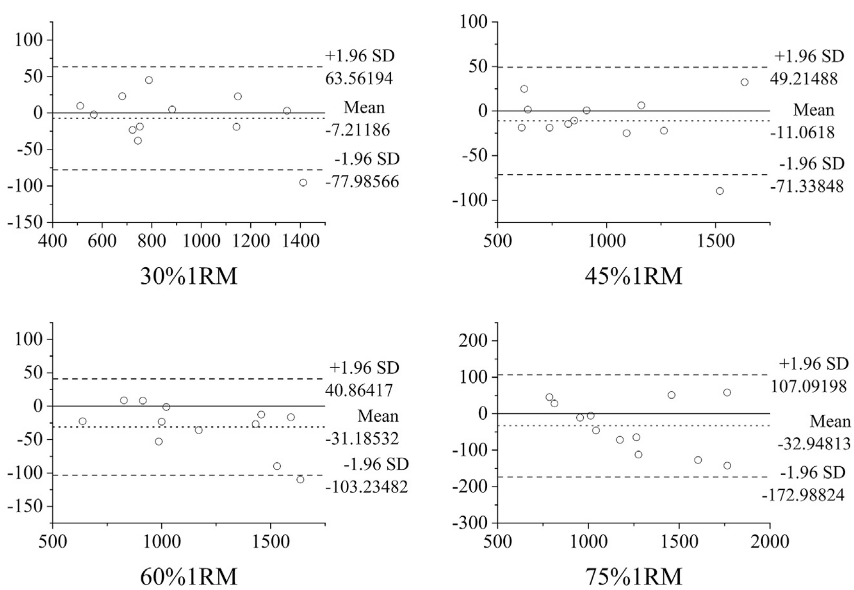



**Figure 3. Bland-Altman plots of $P_{peak}$ of Jueying and GymAware at 30%, 45%, 60%, and 75% 1RM**

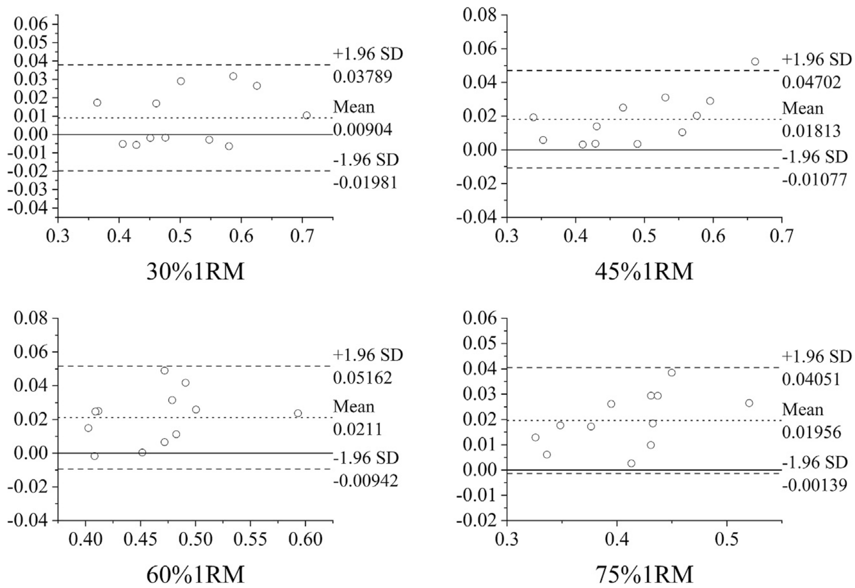



**Figure 4. Bland-Altman plots of $V_{mean}$ of Jueying and GymAware at 30%, 45%, 60%, and 75% 1RM**

Due to the difference in working principles, there was systematic deviation between data obtained from Jueying and GymAware; however, there was still a high correlation, consistency, and small difference between the two devices. For multiple tests, the device could also show good test-retest reliability. In future research, we hope to further evaluate the reliability and validity of Jueying in other types of resistance training.

## Limitations of the study

There are some limitations that need to be considered in the current research. First of all, this study only tested the Smith machine back squat movement, and we could get effective and reliable data for this movement, but we could not guarantee the same conclusions when testing other movements, as the test results of different movements were very likely to be different.[18] Secondly, in order to eliminate the influence of irrelevant factors, the tests of this study were completed on the Smith machine. In actual training, free movement is more common; therefore, the accuracy of this device for free movement needs further verification. Finally, the comparison standard for the validity of this study was only

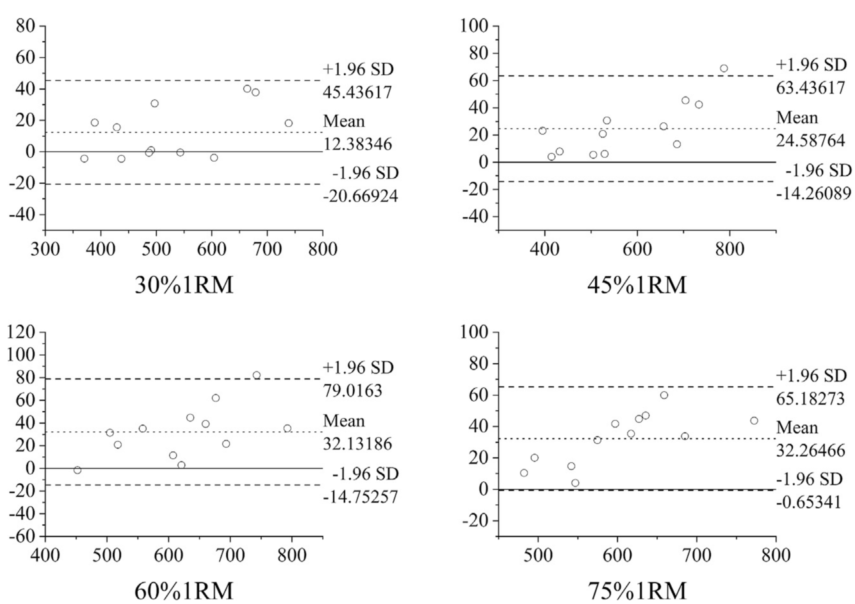



**Figure 5. Bland-Altman plots of $P_{mean}$ of Jueying and GymAware at 30%, 45%, 60%, and 75% 1RM**

Table 3. Test-retest reliability assessment of individual loads for Jueying

| Variable | Load | First session | | Second session | | | |
|---|---|---|---|---|---|---|---|
| | | Average (mean ± SD) | Standard error | Average (mean ± SD) | Standard error | Mean difference | ICC |
| $V_{peak}$ (m/s) | 30% 1RM | 0.87 ± 0.35 | 0.37 | 0.92 ± 0.29 | 0.31 | −0.06 | 0.89 |
| | 45% 1RM | 0.82 ± 0.20 | 0.21 | 0.81 ± 0.20 | 0.20 | 0.01 | 0.95 |
| | 60% 1RM | 0.81 ± 0.18 | 0.19 | 0.80 ± 0.13 | 0.14 | 0.01 | 0.91 |
| | 75% 1RM | 0.76 ± 0.18 | 0.18 | 0.75 ± 0.12 | 0.13 | 0.01 | 0.79 |
| $P_{peak}$ (w) | 30% 1RM | 986 ± 480 | 502 | 1080 ± 436 | 454 | −94 | 0.91 |
| | 45% 1RM | 1067 ± 328 | 343 | 1061 ± 335 | 348 | 6 | 0.95 |
| | 60% 1RM | 1231 ± 388 | 400 | 1201 ± 287 | 288 | 29 | 0.91 |
| | 75% 1RM | 1270 ± 400 | 391 | 1252 ± 305 | 315 | 17 | 0.84 |
| $V_{mean}$ (m/s) | 30% 1RM | 0.53 ± 0.16 | 0.17 | 0.55 ± 0.12 | 0.12 | −0.02 | 0.83 |
| | 45% 1RM | 0.51 ± 0.08 | 0.08 | 0.49 ± 0.08 | 0.08 | 0.02 | 0.89 |
| | 60% 1RM | 0.46 ± 0.07 | 0.07 | 0.45 ± 0.05 | 0.06 | 0.01 | 0.82 |
| | 75% 1RM | 0.41 ± 0.06 | 0.06 | 0.39 ± 0.05 | 0.05 | 0.01 | 0.88 |
| $P_{mean}$ (w) | 30% 1RM | 538 ± 169 | 177 | 568 ± 125 | 131 | 29 | 0.82 |
| | 45% 1RM | 599 ± 118 | 124 | 579 ± 113 | 117 | 20 | 0.92 |
| | 60% 1RM | 615 ± 108 | 113 | 599 ± 99 | 103 | 16 | 0.89 |
| | 75% 1RM | 598 ± 93 | 391 | 579 ± 81 | 85 | 18 | 0.90 |

GymAware. Although this device has been proven to have good reliability and validity, it still needs to be further studied by means such as a dynamometer or high-speed camera.

## Conclusions

In conclusion, Jueying provides a function of measuring velocity and power during resistance training. As far as Smith machine back squat training is concerned, its validity and reliability have been verified. The device can be applied to sports practice, and it can provide effective and reliable data to provide a reference for the arrangement of training.

## STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- KEY RESOURCES TABLE
- RESOURCE AVAILABILITY
  - Lead contact
  - Materials availability
  - Data and code availability
- EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS
  - Human participants
- METHOD DETAILS
  - Experimental approach to the problem
  - Procedures
- QUANTIFICATION AND STATISTICAL ANALYSIS
  - Statistical analysis

## ACKNOWLEDGMENTS

The authors express their gratitude to the athletes who participated in the study. The authors acknowledge the support from the Fundamental Research Funds for Central Universities (grant number: 2021TD010).

## AUTHOR CONTRIBUTIONS

H.Q.: literature review, data collection, data analysis and interpretation, writing of the manuscript; D.Q.: research concept and study design, statistical analyses, editing a draft of the manuscript; S.X.: research concept and study design, reviewing a draft of the manuscript; Y.S.: research concept and study design, reviewing a draft of the manuscript.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

Received: April 4, 2023
Revised: September 11, 2023
Accepted: November 22, 2023
Published: November 25, 2023

## REFERENCES

1. Abernethy, P., Wilson, G., and Logan, P. (1995). Strength and Power Assessment. Sports Med. *19*, 401–417.
2. Hass, C.J., Feigenbaum, M.S., and Franklin, B.A. (2001). Prescription of Resistance Training for Healthy Populations. Sports Med. *31*, 953–964.
3. Peterson, M.D., Rhea, M.R., and Alvar, B.A. (2004). Maximizing strength development in athletes: a meta-analysis to determine the dose-response relationship. J. Strength Cond. Res. *18*, 377–382.
4. González-Badillo, J.J., and Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. Int. J. Sports Med. *31*, 347–352.
5. González-Badillo, J.J., Yañez-García, J.M., Mora-Custodio, R., and Rodríguez-Rosell, D. (2017). Velocity Loss as a Variable for Monitoring Resistance Exercise. Int. J. Sports Med. *38*, 217–225.
6. Sánchez-Medina, L., and González-Badillo, J.J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med. Sci. Sports Exerc. *43*, 1725–1734.
7. Sindiani, M., Lazarus, A., Iacono, A.D., and Halperin, I. (2020). Perception of changes in bar velocity in resistance training: Accuracy levels within and between exercises. Physiol. Behav. *224*, 113025.
8. Stone, M.H., O'Bryant, H.S., McCoy, L., Coglianese, R., Lehmkuhl, M., and Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. J. Strength Cond. Res. *17*, 140–147.
9. Courel-Ibáñez, J., Martínez-Cava, A., Morán-Navarro, R., Escribano-Peñas, P., Chavarren-Cabrero, J., González-Badillo, J.J., and Pallarés, J.G. (2019). Reproducibility and Repeatability of Five Different Technologies for Bar Velocity Measurement in Resistance Training. Ann. Biomed. Eng. *47*, 1523–1538.
10. Garnacho-Castaño, M.V., López-Lastra, S., and Maté-Muñoz, J.L. (2015). Reliability and validity assessment of a linear position transducer. J. Sports Sci. Med. *14*, 128–136.
11. Lake, J.P., Augustus, S., Austin, K., Mundy, P., McMahon, J.J., Comfort, P., and Haff, G.G. (2018). The Validity of the Push Band 2.0 during Vertical Jump Performance. Sports (Basel, Switzerland) *6*, 140.
12. Harris, N.K., Cronin, J., Taylor, K.-L., Boris, J., and Sheppard, J. (2010). Understanding Position Transducer Technology for Strength and Conditioning Practitioners. Strength Cond. J. *32*, 66–79.
13. Argus, C.K., Gill, N.D., Keogh, J.W., and Hopkins, W.G. (2011). Acute Effects of Verbal Feedback on Upper-Body Performance in Elite Athletes. J. Strength Cond. Res. *25*, 3282–3287.
14. Argus, C.K., Gill, N.D., and Keogh, J.W.L. (2012). Characterization of the Differences in Strength and Power Between Different Levels of Competition in Rugby Union Athletes. J. Strength Cond. Res. *26*, 2698–2704.
15. Dorrell, H.F., Moore, J.M., Smith, M.F., and Gee, T.I. (2019). Validity and reliability of a linear positional transducer across commonly practised resistance training exercises. J. Sports Sci. *37*, 67–73.
16. Banyard, H.G., Nosaka, K., Sato, K., and Haff, G.G. (2017). Validity of Various Methods for Determining Velocity, Force, and Power in the Back Squat. Int. J. Sports Physiol. Perform. *12*, 1170–1176.
17. Grgic, J., Scapec, B., Pedisic, Z., and Mikulic, P. (2020). Test-Retest Reliability of Velocity and Power in the Deadlift and Squat Exercises Assessed by the GymAware PowerTool System. Front. Physiol. *11*, 561682.
18. Orange, S.T., Metcalfe, J.W., Marshall, P., Vince, R.V., Madden, L.A., and Liefeith, A. (2020). Test-Retest Reliability of a Commercial Linear Position Transducer (GymAware PowerTool) to Measure Velocity and Power in the Back Squat and Bench Press. J. Strength Cond. Res. *34*, 728–737.
19. Grgic, J., Lazinica, B., Garofolini, A., Schoenfeld, B.J., Saner, N.J., and Mikulic, P. (2019). The effects of time of day-specific resistance training on adaptations in skeletal muscle hypertrophy and muscle strength: A systematic review and meta-analysis. Chronobiol. Int. *36*, 449–460.
20. Haff, G.G., and Nimphius, S. (2012). Training Principles for Power. Strength Cond. J. *34*, 2–12.
21. Hopkins, W.G., Marshall, S.W., Batterham, A.M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. Med. Sci. Sports Exerc. *41*, 3–13.
22. Atkinson, G., and Nevill, A.M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med. *26*, 217–238.
23. Koo, T.K., and Li, M.Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J. Chiropr. Med. *15*, 155–163.

# STAR★METHODS

## KEY RESOURCES TABLE

| REAGENT or RESOURCE | SOURCE | IDENTIFIER |
|---|---|---|
| Software and algorithms | | |
| SPSS | IBM | RRID:SCR_002865 |
| Origin | originlab | RRID:SCR_014212 |
| Other | | |
| Jueying | Beijing Sport University | N/A |
| GymAware | Kinetic Performance | https://gymaware.com/ |

## RESOURCE AVAILABILITY

### Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the Lead Contact, De-xing Qian (qiandexing@bsu.edu.cn).

### Materials availability

This study did not generate new unique reagents.

### Data and code availability

- All data reported in this paper will be shared by the lead contact upon request.
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

## EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

### Human participants

Twelve male participants (age: 24 ± 2 years) with resistance training experience volunteered to take part in the study. All of the participants are from Asian descent. All participants were healthy Chinese university students and had the ability to lift at least 100% of their body mass in the back squat. All participants were free from injury and had at least one year of resistance training experience prior to tests. All participants were informed of the benefits and risks of participating in the study and provided their written informed consent before being enrolled in the study. All tests were conducted at approximately the same time of the day (±1 hours) and under similar environmental conditions (20 ~ 22°C), to avoid the possible confounding effect of circadian variation.[19] Protocols were submitted to, and approved by the Sports Science Experiment Ethics Committee of Beijing Sport University in line with the Helsinki Declarations for research with human volunteers.

## METHOD DETAILS

### Experimental approach to the problem

This study collected and analyzed the velocity and power of two tests, to evaluate the validity and test-retest reliability of Jueying. Formal tests should be conducted at least 48 hours after completion of the weight test and 1RM test. Participants completed two sessions, each one week apart. Depending on the training phase and exercise selection, resistance training aimed at improving muscular power is recommended to be performed using loads ranging from 30 ~ to 90% of 1RM.[20] Therefore, when exploring the reliability of velocity and power in resistance exercises, it was important to use a broad spectrum of loads. In this experiment, tests with different loads were arranged. In this study, participants completed Smith machine back squats under different load conditions, loads used were 30%, 45%, 60%, and 75% of 1RM. The study determined the validity of Jueying by comparing data collected by Jueying and GymAware. The test-retest reliability of Jueying was determined by comparing data measured in two tests.

### Procedures

#### *1RM test*

Jueying and GymAware's assessments of power were based on the weight of the participant. Therefore, the participant's weight was measured before testing. Before the 1RM test protocol, participants first performed a general aerobic warm-up (5 ~ 10 minutes) to avoid injuries. Participants then performed a specific warm-up consisting of 10 repetitions of the squat exercise at 40% of their estimated 1RM and 5 repetitions at 60% of their estimated 1RM.

1RM test started after warming up. Participants completed 8 ~ 10 repetitions at 50% 1RM. After 3-minute rest, the process was repeated at 75% 1RM for 3 ~ 5 repetitions. After a further 3-minute rest, participants completed 1 repetition at 95% 1RM. After an extended rest period of 5 minutes, they attempted their first 1RM trial. According to the outcome of the attempt, the subsequent trial was completed with either an increased or decreased load. All 1RM values were determined in 5 attempts.

### *Data acquisition*

The cables from Jueying and GymAware were simultaneously attached to one side of the Smith machine barbell, perpendicular to the ground. Both systems were calibrated before each testing session. Participants warmed up before the test to avoid injuries. After warming up, participants proceeded with the smith machine back squat test with the incremental load. All participants were asked to perform a single repetition with 4 different loads. Loads used were 30%, 45%, 60% and 75% of 1RM. Each trial was separated by a 2-minute passive rest. At the beginning of the test, participants raised the barbell to an upright standing position with the feet shoulder-width apart. When instructed by the tester, participants completed one repetition in the regular squat position and returned to the upright standing position, and then descended downward and returned to the upright standing position with maximal voluntary speed. To minimize any potential impact of fatigue on the performance, the test load increased gradually. Data from each squat was recorded and stored on a computer and tablet.

## QUANTIFICATION AND STATISTICAL ANALYSIS

### Statistical analysis

The variables used for assessments of both validity and reliability were peak and mean velocity ($V_{peak}$; $V_{mean}$) and power ($P_{peak}$; $P_{mean}$). Pearson correlation coefficient (r) was calculated to evaluate the correlation between two sets of data collected by Jueying and GymAware, and the standardized mean difference (ES) was used to evaluate the magnitude of difference between the devices (trivial 0.2, small 0.6, medium 1.2, and large 2.0).[21] The presence of any fixed and proportional bias between the two devices was determined using linear regression analysis. Fixed bias was identified when the 95% CI of the intercept (*a*) did not overlap with 0, and proportional bias was identified when the slope (*b*) did not contain 1. Bland-Altman plots were also used to evaluate the consistency of data collected by the two devices.

Test-retest reliability denotes the consistency of test results across repeated measurements and shows how much test results are affected by measurement error.[22] To evaluate the test-retest reliability, mean differences between the testing sessions were calculated. Moreover, the intra-class correlation coefficient (ICC) from the two-way random model for a single measure was calculated to assess the absolute agreement between the two trials. ICC was interpreted as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90).[23] All analyses were performed using IBM SPSS for Windows version (IBM. Corp. Armonk, NY) and the significance level was set to 0.05.

Bland-Altman plots were used to analyze the consistency between the monitoring data from GymAware and Jueying. In these plots, the horizontal axis represented the mean value of each monitoring data from GymAware and Jueying, and the vertical axis represented the difference between monitoring data from two devices (x-axis: difference between measures; y-axis: average of measures). The two dashed lines represented the 95% confidence interval of the difference, which was the limit of consistency, and the solid line was the mean value of the difference. The fewer points outside the consistency interval, the better the consistency between the two types of data.