Validity of Various Methods for Determining Velocity, Force and Power in the Back Squat

Harry G. Banyard¹, Kazunori Nosaka¹, Kimitake Sato², G. Gregory Haff¹

¹Centre for Exercise and Sports Science Research (CESSR), School of Medical and Health Science, Edith Cowan University, Joondalup, Western Australia, Australia
²Department of Sport, Exercise, Recreation, and Kinesiology, East Tennessee State University, Johnson City, Tennessee, United States

Correspondence to:
Harry G Banyard
School of Medical and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup, WA, 6027
AUSTRALIA
E-mail address: h.banyard@ecu.edu.au

Preferred Running Head
Validity of methods to determine velocity, force and power

Abstract Word Count
249

Text-Only Word Count
3492

Number of Figures and Tables
8 figures.

Key Words: Athlete Monitoring, Inertia Sensor, Accelerometer, Linear Position Transducer, Force Plate
Validity of Various Methods for Determining Velocity, Force and Power in the Back Squat

ABSTRACT

Purpose: This investigation examined the validity of two kinematic systems for assessing mean velocity (MV), peak velocity (PV), mean force (MF), peak force (PF), mean power (MP), and peak power (PP) during the full depth free-weight back squat performed with maximal concentric effort. Methods: Ten strength-trained men (26.1±3.0 y; 1.81±0.07 m; 82.0±10.6 kg) performed three 1-repetition maximum (1RM) trials on three separate days, encompassing lifts performed at six relative intensities including 20, 40, 60, 80, 90, and 100% of 1RM. Each repetition was simultaneously recorded by a PUSH™ band, commercial linear position transducer (LPT) (GymAware [GYM]), and compared with measurements collected by a laboratory based testing device consisting of four LPTs and a force plate. Results: Trials 2 and 3 were used for validity analyses, combining all 120 repetitions indicated the GYM was highly valid for assessing all criterion variables while the PUSH™ was only highly valid for estimations of PF (r=0.94; CV=5.4%; ES=0.28; SEE=135.5 N). At each relative intensity, the GYM was highly valid for assessing all criterion variables except for PP at 20% (ES=0.81) and 40% (ES=0.67) of 1RM. Moreover, the PUSH™ was only able to accurately estimate PF across all relative intensities (r=0.92–0.98; CV=4.0–8.3%; ES=0.04–0.26; SEE=79.8–213.1 N). Conclusions: The PUSH™ accuracy for determining MV, PV, MF, MP, and PP across all six relative intensities was questionable for the back squat, yet the GYM was highly valid at assessing all criterion variables, with some caution given to estimations of MP and PP performed at lighter loads.
INTRODUCTION

Assessments of velocity, force and power are often employed to monitor training induced adaptations.\(^1-3\) For elite athletes, changes in these measures can be minor, yet significant. As a consequence, equipment used to monitor changes in performance should be precise. In a laboratory based environment, linear position transducers (LPTs) are often used to accurately measure velocity, force plates ascertain ground reactions forces, and a combination of LPTs and force plates can be employed to estimate power output.\(^4-7\) Importantly, laboratory based testing is considered the “gold standard” for data collection, yet is limited due to the large expense, transportation difficulties, and practical complications that can arise from testing with large groups of team sport athletes. Consequently, several field based devices including portable LPTs, accelerometers, and inertial sensors (combination of accelerometer and gyroscope) have been invented to overcome these limitations.\(^8-11\)

However, it is important to determine the devices accuracy to ensure that training decisions are not made as a result of device measurement error.

One LPT device scientifically determined to accurately assess kinematic variables is the GymAware™ (GymAware Power Tool [GYM], Kinetic Performance Technologies, Canberra, Australia).\(^5,7,12\) This portable field based device is a popular tool used to monitor and test athletes. However, it may be cost prohibitive for non-professional sporting teams thus limiting its use by coaches and athletes. Furthermore, since it requires the use of a cable/wire attachment to the barbell, it can be limited in the number of lifting exercises that it can effectively quantify. Consequently, there has been an increased interest in wireless measurement tools to assess kinematic variables without impeding lifting performance due to direct attachments.
Recently, a wearable inertia sensor (PUSH™ band, PUSH Inc., Toronto, Canada) has been developed to measure velocity during resistance training exercises. In addition, it has been suggested that force and power can be accurately estimated from the determined velocity of movement. Presently, only two studies have validated the PUSH™ with one study employing a Smith machine exercise, while the other investigated dumbbell exercises. Interestingly, both studies suggested the PUSH™ accurately measured both mean and peak velocity. However, no previous study has examined the validity of the PUSH™ with the use of a large mass free-weight exercise, such as the back squat, across a variety of training intensities. Importantly, the PUSH™ is relatively inexpensive compared to the GYM but since many sporting teams already possess GYM technology, evaluating the accuracy of measurement devices such as the PUSH™ is highly beneficial. Therefore, the purpose of this study was to investigate the ability of two field-based devices to accurately measure velocity, force and power in the back squat exercise compared to laboratory based testing equipment.

METHODS

Participants

Ten male resistance-trained volunteers took part in this study (26.1±3.0 y; 1.81±0.07 m; 82.0±10.6 kg). All participants could perform the full back squat with at least 1.5 times their body mass, had at least 6 months of resistance training experience, and were injury free. The participant’s average one repetition maximum (1RM) back squat and 1RM to body mass ratio were 142.1±33.8 kg and 1.72±0.23 kg, respectively. All participants provided written informed consent prior to participation in the present study in accordance with the ethical requirements of Edith Cowan
Study Design

This study assessed the validity of the PUSH™ (PUSH Inc., Toronto, Canada) and GYM (GymAware Power Tool, Kinetic Performance Technologies, Canberra, Australia) devices in order to determine the accuracy of mean velocity (MV), peak velocity (PV), mean force (MF), peak force (PF), mean power (MP) and peak power (PP) during two incremental back squat 1RM assessments compared to a laboratory based testing (LAB) device (i.e. 4 LPTs and force plate). All participants performed an initial 1RM assessment (trial 1) followed by two further 1RM trials (trials 2 and 3) with each trial separated by 48 hours. The initial 1RM assessment was done so that accurate relative 1RM loads could be lifted in the remaining two 1RM sessions. Consequently, the field and laboratory devices were only used to measure the criterion variables during trials 2 and 3.

Procedures

1RM Assessment

1RM assessments were performed in a power cage (Fitness Technology, Adelaide, Australia) using a 20 kg barbell (Eleiko®; Halmstad, Sweden). The warm-up and procedures were identical in all 1RM assessments with participants commencing the session by pedalling on a cycle ergometer (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) for five minutes at 100 W and 60 revolutions per minute, performing three minutes of dynamic stretching, followed by a back squat protocol consisting of three repetitions at 20%, 40%, and 60% of 1RM, and 1 repetition at 80%, 90%, and 100% of 1RM. These relative loads were estimated for session 1. Reliability of this method to determine 1RM has been previously
established (ICC = 0.99; CV = 2.1%; SEM = 2.9 kg; effect size [ES] = 0.03). Following successful 1RM attempts, the weight was increased between 0.5 and 2.5 kg until no further weight could be lifted, with a maximum of five 1RM attempts given. Participants were instructed to apply constant downward pressure on the barbell and to keep their feet in contact with the floor for the entirety of the repetition. Passive recovery time between warm-up sets was two minutes while three minutes rest period was given between 1RM attempts. For each back squat repetition, the eccentric phase was performed in a controlled manner at a self-selected velocity until full knee flexion was achieved whereas the concentric phase was completed as fast and impulsively as possible with the aid of verbal encouragement. Peak knee flexion angle at the bottom of the squat (123.1±11.2°) was measured in trial 1 using a goniometer. This knee angle at the bottom of the squat corresponded to a specific barbell depth recorded on a LabView analysis program. The recorded barbell depth at full knee flexion was then monitored by visual displacement curves on the LabView analysis program to ensure the same barbell depth was maintained for each repetition in all trials.

**Data Acquisition**

For trials 2 and 3, each repetition was simultaneously measured using the PUSH™, GYM and LAB methods. The PUSH™ was worn on the right forearm immediately inferior to the elbow crease with the on/off button located proximally (as suggested by the manufacturer). Data obtained from the PUSH™ were recorded at a sampling rate of 200 Hz via Bluetooth™ connection with a smartphone (iPhone, Apple Inc., California, USA) using a proprietary application. In contrast, the GYM data were transmitted via Bluetooth™ to a tablet (iPad, Apple Inc., California, USA). The GYM recorded the displacement time curve data by determining changes in the barbell position. The device sampled and time stamped the changes in barbell
position at 20 ms time points,\textsuperscript{18} which was down sampled to 50 Hz for analysis.\textsuperscript{7} Velocity and acceleration data were then calculated from the first and second derivate of the change in barbell position with respect to time. Force values were determined from the system mass multiplied by the acceleration data, where system mass was the barbell load plus the relevant body mass of the participant. Power values were evaluated from the product of the force and velocity curve data. Comparatively, the PUSH™ determined velocity by measuring the linear accelerations and angular velocities of the movement where vertical velocity was calculated by the integration of acceleration with respect to time.\textsuperscript{13} Similar to the GYM, force estimations by the PUSH™ were calculated from the system mass multiplied by the acceleration data whereas power values were determined from the product of the force and velocity curve data.

For the LAB system, all kinetic and kinematic data were collected using similar methodology to previous research.\textsuperscript{15,16,18} Briefly, velocity measures were captured from four LPTs (Celesco PT5A-250; Chatsworth, California, USA) that were mounted to the top of the squat rack with two positioned in an anterior and posterior location on both the left and right side of the barbell.\textsuperscript{16} The utilization of four LPTs allowed for the quantification of both vertical and horizontal movements for both sides of the barbell and establish a more accurate “central displacement” position.\textsuperscript{16} Both MF and PF were obtained directly from the quantification of ground reaction forces with the use of a force plate (AMTI BP6001200, Watertown, Massachusetts, USA). Power measures were calculated from the product of the direct measurement of ground reaction force and bar velocity.\textsuperscript{16,19} The LPT and force plate data were collected through a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000 Hz. All data
were collected and analysed using a customised LabVIEW program (National Instruments, Version 14.0). All signals were filtered with a 4th order-low pass Butterworth filter with a cut-off frequency of 50 Hz. The total tension on the barbell as a result of the transducer attachments was 17.25 N in a superior direction, which was accounted for in all calculations.

Values of MV, MF, and MP obtained by the PUSH™, GYM and LAB, were determined as the average of the data collected during the concentric phase of the movement (greatest descent to standing position), whereas PV, PF, and PP were determined as the maximum value in the same concentric period. From trials 2 and 3, only one repetition (fastest average concentric velocity determined from LAB data) was selected from each of the sets performed at 20, 40, and 60% of 1RM to ensure an equal number of repetitions were used for the validity analyses from each relative intensity.

**Statistical Analyses**

Validity analyses of the GYM and PUSH™ were determined by 1) combining all 120 repetitions performed by each individual regardless of relative load, and 2) examining the devices at each relative intensity (20, 40, 60, 80, 90, and 100% of 1RM). The validity of the field-based devices was determined from the magnitude of the Pearson product moment correlation (r), coefficient of variation (CV), and the ES.

For this study, the field based devices were deemed highly valid if they met the three following criteria: very high correlation (>0.70), moderate CV (≤10%), and a trivial or small ES (<0.60) based on the Hopkins modified Cohen scale (<0.20, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; 2.0-4.0, very large; >4.0, extremely large). The standard error of the estimate (SEE) was also determined. Confidence limits for all validity analyses were set at 95%. Systematic bias between
LAB and field based methods for each criterion measure was assessed using a repeated measures analysis of variance (ANOVA) with correction for sphericity and a type-I error rate set at $\alpha<0.05$ (IBM SPSS version 22.0, Armonk, New York, USA). Tukey post hoc comparisons were utilized when appropriate. Data are reported as mean $\pm$ SD unless stated otherwise.

RESULTS

Average values of mean and peak velocity, force and power at each relative load are displayed in Figure 1. Systematic bias was evident for PUSH™ estimations of MF and PP, and GYM estimates of PF and PP (Figure 1). When all 120 repetitions were combined, the PUSH™ was highly valid for estimations of PF only (Figure 2). By comparison, the GYM was highly valid for all criterion variables.

When the data were analysed at the six relative intensities, the GYM was highly valid across all relative loads for values of MV, PV, MF, and PF (Figures 3–6). However, MP and PP values estimated by the GYM were not highly valid at 20 and 40% of 1RM due to the moderate ES (Figure 7C & 8C). The PUSH™ was highly valid at all relative intensities for estimations of PF only (Figure 6). More specifically, the PUSH™ did not meet our criteria of high validity for estimations of MV at greater than or equal to 80% of 1RM (Figure 3); PV above 20% of 1RM (Figure 4); MF at or below 90% of 1RM (Figure 5); MP at 40% of 1RM and above (Figure 7); and PP at all relative intensities (Figure 8).

DISCUSSION

The aim of this study was to assess the validity of two field based devices to accurately determine mean and peak values of velocity, force and power in the back squat exercise. When all repetitions were combined for analyses regardless of the relative load, the GYM was valid in the assessment of all criterion variables yet the
PUSH™ only accurately estimated PF. Although this information is helpful and allows us to compare our results with previous findings,\textsuperscript{13,14} it is important to understand the accuracy of field based devices at a variety of relative intensities since most athletes will perform resistance-training exercises with varying loads depending on the phase of the periodized training plan. Thus, when the data were analysed for each relative load, the GYM accurately estimated all criterion variables except for PP, which was invalid at lighter loads, more specifically, at 20 and 40% of 1RM in the back squat exercise. By comparison, the PUSH™ was only able to accurately estimate PF across all relative intensities. Moreover, MV, PV, MF, MP, and PP quantified by the PUSH™ across all six relative loads were questionable.

For measurements of MV, the PUSH™ was less valid at heavier loads when compared to LAB results. Specifically, the greatest lack of validity was seen at loads equal to and above 80% of 1RM, which is problematic for athletes using the device when training with higher intensities when targeting maximal strength development. Despite this shortcoming, the PUSH™ band met the validity criteria in the measurement of MV at light and moderate loads (<60% of 1RM). Interestingly, for measurements of PV the PUSH™ was only valid at the lightest load tested (20% of 1RM). Based on the results of this study, we would suggest the PUSH™ can accurately measure MV at light and moderate relative loads, typically used in the back squat during power based training programs, but is questionable for measurements of PV across the relative intensity spectrum.

As previously mentioned, two studies have investigated the validity of the PUSH™ to measure MV and PV. Balsalobre-Fernández et al.\textsuperscript{13} compared the measurements of the PUSH™ to a single LPT (T-force, Ergotech, Murcia, Spain) in the full depth Smith machine back squat. Ten physically active male participants
performed five sets of three repetitions with the five incremental loads pertaining to 20, 40, 60, and 70 kg (anecdotally suggested to represent 25 to 85% of 1RM for each participant). When all 150 repetitions (every repetition for each subject) were combined for their validity analyses the PUSH™ accurately measured MV ($r=0.85$; SEE=$0.08 \text{ m}\cdot\text{s}^{-1}$) and PV ($r=0.91$; SEE=$0.10 \text{ m}\cdot\text{s}^{-1}$). Interestingly, the correlation and measurement error results from Balsalobre-Fernández et al.\textsuperscript{13} were comparatively similar to the PUSH™ measurements of MV ($r=0.93$; SEE=$0.10 \text{ m}\cdot\text{s}^{-1}$) and PV ($r=0.91$; SEE=$0.15 \text{ m}\cdot\text{s}^{-1}$) reported in the present study. However, the present study would suggest the PUSH™ was not accurate for measuring MV and PV due to the poor CV% and were not consistent with those reported by Balsalobre-Fernández et al.\textsuperscript{13} for a similar action. This may be due to the difference in barbell paths between Smith machine (fixed linear action) and free-weight back squat.

Similarly, Sato et al.\textsuperscript{14} reported the validity of the PUSH™ for measurements of MV and PV compared to a 3D motion analysis capture system (VICON-Peak, Oxford Metrics, Oxford, UK) in the dumbbell bicep curl and dumbbell shoulder press exercises. Five recreationally trained participants performed both exercises with two sets of 10 repetitions at 4.54 kg, and two sets of 10 repetitions at 6.82 kg. Similar to Balsalobre-Fernández et al.,\textsuperscript{13} Sato et al.\textsuperscript{14} combined all repetitions (200 repetitions) regardless of load for statistical analyses and concluded the PUSH™ was highly valid at measuring MV and PV for the bicep curl (MV: $r=0.86$, SEE=$0.09 \text{ m}\cdot\text{s}^{-1}$; PV: $r=0.80$, SEE=$0.16 \text{ m}\cdot\text{s}^{-1}$) and shoulder press exercises (MV: $r=0.88$, SEE=$0.06 \text{ m}\cdot\text{s}^{-1}$; PV: $r=0.92$, SEE=$0.11 \text{ m}\cdot\text{s}^{-1}$). These correlations and measurement error findings also compare well with the results from the present study even though the modes of exercises investigated were different between studies but like the Balsalobre-Fernández et al.,\textsuperscript{13} study, Sato et al.\textsuperscript{14} also did not report the CV. Although the
findings of previous research validating the PUSH™ are helpful and accurately reflect how the data were analysed, they are somewhat limited since the validity of the PUSH™ was not reported at specific relative intensities. Importantly, the present study found the accuracy of the PUSH™ varies depending on the intensity lifted, which is important to discern as athletes often train at a variety of relative loads throughout the training year. Nevertheless, the aforementioned studies observed similar velocities to those determined in the present study when all repetitions were combined for analyses regardless of the load. Interestingly, Sato et al. and Balsalobre-Fernández et al. detected systematic bias for estimations of MV and PV by the PUSH™ which was not observed in the present study.

Unsurprisingly, the GYM accurately measured MV and PV across all relative loads. However, there were minor but non-significant differences observed between GYM (1 LPT) and LAB (4 LPTs) assessment of MV and PV. This was likely due to slight variations in horizontal and vertical displacement on either side of the barbell (bar path) that can occur when using a single LPT. This has been observed in previous research where Cormie et al. assessed differences in the measurement of PV between 1 LPT and 2 LPTs for the jump squat exercise performed at 30 and 90% of 1RM. They reported the 1 LPT system significantly (p<0.05) over predicted measurements of PV at 90% but not 30% of 1RM compared to 2 LPTs. However, contrary to the findings of Cormie et al. we did not find any significant differences between the GYM and LAB for MV or PV at any relative intensity.

To our knowledge this is the first study to assess the accuracy of the PUSH™ to estimate force and power during the back squat. Uniquely, the PUSH™ accurately estimated PF across all relative intensities compared to LAB, yet was only highly valid for the estimation of MF at 1RM. In addition, the PUSH™ estimations of MP
and PP were not highly valid at all relative intensities except for MP at 20% of 1RM.

Furthermore, the PUSH™ estimates of MP appeared to follow a linear trend across the six relative loads, which are not typically reported in the scientific literature.4

The present study detected systematic bias in the PUSH™ estimations of PP and MF but not PF. Similarly, previous studies have identified the presence of systematic bias (p<0.05) in accelerometers, most notably for estimations of PF and PP compared to direct assessments of ground reaction forces from a force plate (Force) and the combination of a force plate and LPT (Power) methodologies.8,12 For example, Comstock et al.8 observed systematic bias for an accelerometer (Myotest®, Myotest Inc, Sion, Switzerland) in the estimation of PF and PP compared to a force plate (Ballistic Measurement System Innervations Inc, Fitness Technology force plate, Skye, Australia) and LPT (Celesco PT5A-250; Chatsworth, California, USA) method with the bench throw and jump squat exercises performed at 30% of 1RM. Comparatively, the present study also observed systematic bias for estimations of PF and PP by the GYM, specifically for PP at 20 and 40% of 1RM. Importantly, the systematic bias observed for estimations of PF and PP from a LPT at light loads has previously been reported. Cormie et al.19 also reported the presence of systematic bias for estimations of PF and PP derived with one LPT compared to a force plate and LPT method of force/power assessment at 30% of 1RM for the jump squat exercise. Despite the presence of systematic bias in the present study for estimations of PF and PP by the GYM, the LPT was still highly valid.

The systematic bias observed for the GYM was also in accordance with Crewther et al.12 who compared the accuracy of a LPT (GymAware Power Tool, Kinetic Performance Technologies, Canberra, Australia) and accelerometer (Myotest®, Myotest Inc. Switzerland) with a force plate (Kistler, Kistler Instruments
Ltd, Farnborough, USA) to determine PF and PP with increasing loads (20, 40, 60, and 80 kg) in the jump squat exercise. Systematic bias was detected at the lighter loads in the estimation of PF (20 and 40 kg) and PP (20 kg) for the GYM. Furthermore, moderate to high validity for PF and PP estimations in both the LPT (PF: $r=0.59$ to $0.87$, SEE=$39$ to $202$ N; PP: $r=0.62$ to $0.82$, SEE=$45$ to $401$ W) and accelerometer (PF: $r=0.87$ to $0.97$, SEE=$7$ to $171$ N; PP: $r=0.66$ to $0.90$, SEE=$-180$ to $614$ W) were reported. If one compares the results of Crewther et al.\(^{12}\) to the present study, the PUSH™ compares well with accelerometer devices for estimations of PF and PP. However, based on the correlation and SEE data, it appears the GYM is more accurate in the current study compared to previous research, possibly due to the less rapid speeds observed in the back squat exercise.

Differences observed for the PUSH™ and GYM estimations of force and power compared to the LAB system were likely due to a multitude of factors. These include the different sampling frequencies used with each device,\(^{25}\) disparities in the measurement of bar movements in the horizontal plane,\(^{17}\) and method of calculating force and power through the differentiation of accelerations and velocities which can magnify errors seen in data acquisition.\(^{12}\)

**Conclusions**

Our results suggest that even though systematic bias was present for the GYM assessment of PF and PP, the GYM is a valid field based device, which can accurately measure velocity, and is highly valid for the estimations of force. However, the GYM was problematic for the estimation of MP and PP at lighter loads in the back squat exercise. By comparison, the PUSH™ was able to accurately estimate PF at all relative intensities, and determine MV at light to moderate loads. However, the
validity of the PUSH™ to measure anything other than PF in the back squat exercise performed across a spectrum of relative loads appears questionable.

**Practical Applications**

The present study suggests practitioners should be cautious if prescribing/modifying sessional training loads or monitoring training adaptations for any variable other than PF using the PUSH™, particularly at slower velocities. By comparison, the GYM, although not quite as sensitive as LAB testing methods, is highly valid and sensitive enough to be used as a tool to monitor training except for MP and PP at faster velocities.

**Acknowledgements**

The findings from this investigation do not constitute endorsement of any products assessed by the authors or the journal. The Centre for Exercise and Sports Science Research (CESSR) at Edith Cowan University provided financial assistance and all testing equipment.

**REFERENCES**


Figure 1: Mean and peak values of velocity, force, and power. * indicates significant differences between PUSH™ and Laboratory methods. # indicates significant differences between GymAware and Laboratory methods.
Figure 2: Validity of the PUSH™ and GymAware for the measurement of mean velocity (MV), peak velocity (PV), mean force (MF), peak force (PF), mean power (MP), peak power (PP). Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), standard error of the estimate for MV and PV (D), MF and PF (E), and MP and PP (F).
Figure 3: Validity of mean velocity in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.
Figure 4: Validity of peak velocity in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.
Figure 5: Validity of mean force in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.
Figure 6: Validity of peak force in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.
Figure 7: Validity of mean power in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.
Figure 8: Validity of PP in the back squat for the PUSH™ and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1RM compared to Laboratory methods. Forest plots displaying Pearson correlation coefficient (A), coefficient of variation (B), effect size estimates (C), and standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.