Full title: The Reliability and Validity of the Bar-Mounted PUSH Band™ 2.0 During Bench Press with Moderate and Heavy Loads

Running title: Reliability and validity of PUSH Band™ 2.0 during bench press

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The Reliability and Validity of the Bar-Mounted PUSH Band^{TM} 2.0 During Bench Press with Moderate and Heavy Loads

Abstract

The aim of this study was to assess the reliability and validity of the bar-mounted PUSH Band^{TM} 2.0 to determine peak and mean velocity during the bench press exercise with a moderate (60% one repetition maximum [1RM]) and heavy (90% 1RM) load. We did this by simultaneously recording peak and mean velocity using the PUSH Band^{TM} 2.0 and three-dimensional motion capture from participants bench pressing with 60% and 90% 1RM. We used ordinary least products regression to assess within-session reliability and whether the PUSH Band^{TM} 2.0 could accurately predict motion capture velocity. Results showed that PUSH Band^{TM} 2.0 and motion capture peak and mean velocity reliability was acceptable with both loads. While there was a tendency for the PUSH Band^{TM} 2.0 to slightly overestimate peak and mean velocity, there was no fixed bias. However, mean velocity with 60 and 90% 1RM demonstrated proportional bias (differences between predicted and motion capture values increase with magnitude). Therefore, PUSH Band^{TM} 2.0 peak velocity with 60 and 90% 1RM is valid, but mean velocity is not.

Key words: Accelerometer; resistance exercise; method comparison; velocity-based training; athlete monitoring

Introduction

Recently, there has been an increased interest in quantifying resistance exercise intensity and estimating the one repetition maximum (1RM) from barbell velocity because it appears to strongly related to load and resistance exercise intensity (Balsalobre-Fernandez, Munoz-Lopez, Marchante, & Garcia-Ramos, 2018; Jovanovic & Flanagan, 2014; Perez-Castilla, Piepoli, Delgado-Garcia, Garrido-Blanca, & Garcia-Ramos, 2019; Sanchez-Medina & Gonzalez-Badillo, 2011). Based upon these studies, there is some evidence to suggest that load-velocity testing may render 1RM testing unnecessary with some exercises and situations (Gonzalez-Badillo & Sanchez-Medina, 2010). For example, during the Smith machine bench press exercise, increases in mean velocity of 0.07 to 0.09 m/s represented a 1RM increase of 5%. Conversely, a decrease in mean velocity of 0.07 to 0.09 m/s would indicate a 1RM decrease of 5%. However, it should be noted that the predictive ability of the load-velocity relationship does not seem to be as strong during large mass multi-joint free-weight exercises such as the back squat (Banyard, Nosaka, & Haff, 2017) and deadlift (Lake, Naworynsky, Duncan, & Jackson, 2017). While there is still some debate about the use of load-velocity testing in the scientific literature there is an increasing interest in using these methods within strength and conditioning (Harris, Cronin, Taylor, Boris, & Sheppard, 2010; Jovanovic & Flanagan, 2014).

The increasing interest in load-velocity profiling has led to the development of portable velocity measuring devices that have the potential to enable strength and conditioning practitioners to monitor movement velocity during various lifting tasks (Jovanovic & Flanagan, 2014). However, a critical part of selecting the most appropriate measurement device is to assess its validity (Bland & Altman, 1986; Ludbrook, 1997, 2012; Mullineaux, Barnes, & Batterham, 1999; Mundy & Clarke, 2019). This is critical because the validity of a device will determine whether it can be used to accurately measure velocity during resistance exercise performed with sub-maximal loads, particularly as such devices may be used to predict changes in exercise 1RM (Gonzalez-Badillo & Sanchez-Medina, 2010; Perez-Castilla et al., 2019). Additionally, the validity of a device could significantly impact the accuracy of load-velocity testing (Banyard, Nosaka, & Haff, 2017). The PUSH Band™

(PUSH Inc, Toronto, Canada) is a device that uses an accelerometer to provide peak and mean velocity data. The original version of this device was attached to the lifter's forearm via a sleeve (Balsalobre-Fernández, Kuzdub, Poveda-Ortiz, & Campo-Vecino, 2016; Montalvo et al., 2018; Ripley & McMahon, 2016; Sato et al., 2015), however the newest version of this device enables it to be fixed directly to the barbell or on the forearm (PUSH Band 2.0™) (Lake et al., 2018). Additionally, this most recent version uses an accelerometer with a full range of ±16 g, and a sensitivity of 2048 least significant bit/g; its gyroscope has a full range of ±2000 degrees/s, and a sensitivity of 16.4 least significant bit/g. It also now samples at 1000 Hz, but down samples to between 200 and 230 Hz.

While there is some evidence that the original version of the PUSH Band™ is valid when attached to the forearm (Orange et al., 2018; Sato et al., 2015), there is limited research into its validity during the bench press and no research directly examining its validity when it is directly attached to the barbell. For example, Orange et al. (2018) considered the reliability and validity of the PUSH Band™ during free-weight bench press across a range of loads. They concluded that the validity of this device varied according to the load that was lifted and variable that was of interest. Due to the popularity of this device amongst strength and conditioning professionals there is a need to assess the validity of the PUSH Band 2.0™ in non-ballistic exercises, such as the free weight barbell bench press. Additionally, it is important to establish the validity and reliability of the PUSH Band 2.0™ because, unlike previous versions of this device, it attaches directly to the barbell and so data will be processed differently by the proprietary software to calculate peak and mean velocity. Because the bench press requires a relatively simple barbell displacement, and because it is a popular and important upper-body training exercise, it is an excellent exercise to use to determine the validity of the new version of the PUSH Band^{TM} (PUSH Inc, Toronto, Canada).

Therefore, the primary aim of this study was to assess agreement between peak and mean velocity obtained when the PUSH Band^{TM} 2.0 is attached to the barbell during the bench press and derived from three-dimensional motion capture. Based on literature that has assessed the validity of the PUSH Band^{TM} during dumbbell overhead pressing and other resistance exercises (Balsalobre-Fernández et al., 2016; Sato et al., 2015), the null hypothesis that the PUSH Band^{TM} and the criterion method would not agree was tested.

Materials and Methods

Participants

Fourteen men experienced in resistance training (age = 22.2 ± 2.6 years, height = 1.76 ± 0.07 m, body mass = 83.6 ± 14.5 kg, training experience > 3 years, bench press one repetition maximum [1RM] = 99.0 ± 22.8 kg, bench press 1RM relative to body mass = 1.20 ± 0.29 $kg \cdot kg^{-1}$) volunteered for the investigation. Each participant provided written informed consent and the study was approved by an institutional ethics committee and conformed to the principles of the World Medical Association's Declaration of Helsinki.

Procedures

Participants attended the laboratory for one testing session. They performed a non-standardised warm up that included some light exercise to raise body temperature before they performed a variety of dynamic upper-body exercises and sub-maximal bench press repetitions with loads that did not exceed 50% 1RM. They then performed three sets of three repetitions with 60% 1RM before progressing to perform three sets of one repetition with 90% 1RM. These loads were used because research recently demonstrated that similar loads can be used to accurately predict bench press 1RM from a two-point load-velocity relationship (Garcia-Ramos, Haff, Pestana-Melero, & Perez-Castilla, 2018). The participant 1RM was taken from recent training records. Participants rested for three minutes between each set performed during the testing session.

Data Collection

All repetitions were captured concurrently using the PUSH Band^{TM} 2.0 (PUSH Inc, Toronto, Canada) (sampling at 1000 Hz and down sampling to 200-230 Hz for Bluetooth transmission) and a 10-camera, opto-electronic 3D motion analysis system (Vicon T40S, Vicon Motion Systems, Oxford, UK) (sampling at 200 Hz). The PUSH Band^{TM} 2.0 was set to bar-mode and placed upon the centre of the barbell as per manufacturer recommendations. The concentric peak and mean vertical velocity values from each repetition were sent via Bluetooth to an Apple iPhone 6 running the proprietary PUSH application (V4.2.1). Additionally, a single reflective marker (12.6 mm diameter) was attached to the PUSH Band^{TM} 2.0 sleeve directly superior to the centre of the sensor. The motion analysis system recorded the three-dimensional displacements of the marker during each repetition in Vicon Nexus software (V2.6, Vicon Motion Systems, Oxford, UK) after the capture space was calibrated in accordance with manufacturer recommendations. The calibration was re-performed if any of the cameras had a calibration error above 1 mm, and typical residual errors were between 0.3-0.6 mm.

Data Analysis

Barbell displacement-time data were exported to Visual 3D (V6.01.22, C-Motion, Rockville, USA), and barbell velocity was calculated using the finite difference method in Visual 3D. Displacement data were filtered using a fourth order, zero-lag, Butterworth low-pass filter with a cut-off frequency of 12 Hz. Data were visually inspected to assess the effect that different cut-off frequencies (6-20 Hz) had on vertical velocity and 12 Hz was selected because lower cut-off frequencies attenuated peak values. The start of the concentric phase of each repetition was determined as the first frame in which the marker displayed a positive vertical velocity following the eccentric phase (bar lowering), and the end of the concentric phase was identified as the first frame in which the marker displayed a negative vertical velocity after the end of the concentric lifting phase. Peak vertical velocity and mean vertical velocity were subsequently determined from the highest values in the concentric phase and by averaging data over the concentric phase, respectively.

Statistical Analysis

For each of the two load conditions the trial with the highest mean velocity (from the motion capture data) was selected for further analysis and validity was assessed using data from the different methods from this trial. The trials in which the highest mean velocity (from the motion capture data) occurred were identified on a load-by-load and subject-by-subject basis and corresponding peak and mean velocity data from the both methods were taken from these trials (Lake et al., 2018).

Many different statistical tests have been proposed to establish the reliability and validity of measurements within sports science (Mullineaux et al., 1999). Although there is no consensus on the most appropriate test, there are a number of limitations with the more commonly used tests (e.g. correlation, ordinary least-squares regression) (Bland & Altman, 1986; Ludbrook, 1997, 2012; Mullineaux et al., 1999). It is outside the scope of this article to discuss each of these limitations; particularly as they have been discussed extensively elsewhere (readers are referred to Ludbrook (2012), Mullineaux et al. (1999), and Mundy & Clarke (2019)). In brief, it has been stated that the principal limitation of the majority of the more commonly used tests is that they do not assess both fixed (significant fixed difference between the criterion [motion capture] value and the value predicted by the alternative method [PUSH Band™ 2.0]) and proportional bias (significant difference between the criterion [motion capture] value and the value predicted by the alternative method [PUSH Band™ 2.0] that increases proportionally) (Ludbrook, 1997, 2012; Mullineaux et al., 1999). As such, it is suggested that comparative studies should use ordinary least-products regression to robustly assess both of these parameters (Ludbrook, 1997, 2012).

Following checks for normality, uniform distribution and linearity, ordinary least-products regression was used to assess fixed and proportional bias to test the reliability of motion capture and PUSH Band™ 2.0 peak and mean velocity with 60 and 90% 1RM and to test the validity of the PUSH Band™ 2.0 against the criterion motion capture using methods described by Ludbrook (2012). If the 95% confidence interval for the intercept did not include 0, then fixed bias was present. If the 95% confidence interval for the slope did not include 1.0, then proportional bias was present. If fixed or proportional bias was present this meant that the method was either not reliable or could not be used to accurately predict the gold standard peak or mean velocity (3D motion capture). We also used the intraclass correlation coefficient (ICC) and the coefficient of variation (CV – 68% [from 1 SD]) to assess relative and absolute reliability, with acceptable relative reliability set at an ICC value >0.7 (Cortina, 1993) and acceptable absolute reliability set using the criteria recently used in the literature (CV >10% = poor, 5-10% = moderate, <5% = good (Banyard, Nosaka, & Haff, 2017).

Results

The results of the reliability least products regression analysis of the motion capture and PUSH Band^{TM} 2.0 peak and mean velocity are presented in Table 1 and 2 respectively. They show that no fixed or proportional bias were present for both the motion capture and PUSH Band^{TM} 2.0 peak and mean velocity with 60% 1RM and mean velocity with 90% 1RM, indicating that their reliability was acceptable. When more traditional reliability statistics were used, motion capture and PUSH Band^{TM} 2.0 peak and mean velocity with 60 and 90% 1RM demonstrated high relative reliability and good and moderate absolute reliability (Table 3).

****** Tables 1, 2, and 3 near here******

Descriptive data from the peak and mean velocity method comparison are presented in Table 4. These data show that the PUSH Band^{TM} 2.0 significantly overestimated mean velocity with 60 and 90% 1RM and peak velocity with 90%

1RM. However, when data were analysed using least products regression the direction and magnitude of these differences changed. These results are presented in Table 5. It shows that with the exception of peak velocity with 90% 1RM the PUSH Band^{TM} 2.0 slightly overestimated peak and mean velocity. However, because the intercept confidence intervals crossed zero there was no fixed bias (significant fixed difference between the criterion [motion capture] value and the value predicted by the alternative method [PUSH Band^{TM} 2.0]). The confidence intervals from the slope of the mean velocity with 60 and 90% 1RM did not include 1, indicating proportional bias (significant difference between the criterion [motion capture] value and the value predicted by the alternative method [PUSH Band^{TM} 2.0] that increases proportionally). Therefore, PUSH Band^{TM} 2.0 peak velocity with 60 and 90% 1RM can be considered valid, whereas PUSH Band^{TM} 2.0 mean velocity with 60 and 90% 1RM cannot be considered valid.

******Tables 4 and 5 near here******

Discussion

The aim of this study was to assess the validity and reliability of the PUSH Band^{TM} 2.0 during free-weight bench press performance. The results showed that the PUSH Band^{TM} 2.0 was reliable and peak velocity with both loads was valid, but that the PUSH Band^{TM} 2.0 mean velocity did not agree with the motion capture equivalent after demonstrating proportional bias with both loads. These are important findings because to the authors' knowledge this is the first time the validity of the PUSH Band 2.0^{TM} has been studied during free weight bench press exercise. It is particularly important to establish the validity and reliability of the PUSH Band 2.0™ because, unlike previous versions of this device, it attaches directly to the barbell and so the proprietary software uses different data processing to calculate peak and mean velocity. These results will help inform strength and conditioning practitioners about the relative merits of this device particularly with respect to their use to estimate resistance exercise training intensity and 1RM (Gonzalez-Badillo & Sanchez-Medina, 2010).

With regards to the reliability of the PUSH Band™ 2.0, the results of this study support previous work that has shown the reliability of the original and PUSH Band™ 2.0 to be acceptable during dumbbell shoulder press and dumbbell curl (Sato et al., 2015), the Smith machine bench press (Perez-Castilla et al., 2019), the back squat (Balsalobre-Fernández et al., 2016; Banyard, Nosaka, Sato, & Haff, 2017), and vertical jumping (Lake et al., 2018; Montalvo et al., 2018; Ripley & McMahon, 2016). However, this counters other work that has considered its reliability during the bench press (Orange et al., 2018). These results have important implications for strength and conditioning practitioners because they show that the PUSH Band™ 2.0 provides consistent (reliable) peak and mean velocity data. These findings are important for strength and conditioning coaches considering using the PUSH Band™ 2.0 to estimate resistance exercise intensity and 1RM.

When considering the validity of the PUSH Band™ 2.0, the results of this study partially support previous work that has considered its validity during different resistance exercises (Balsalobre-Fernández et al., 2016; Sato et al., 2015). The results of the least products regression analysis on PUSH Band™ 2.0 vs. motion capture showed that PUSH Band™ 2.0 data could accurately predict motion capture peak velocity with both 60 and 90% 1RM. However, the PUSH Band™ 2.0 could not accurately estimate mean velocity with either load. This could have important implications for practitioners, because while peak velocity can provide useful information, particularly during ballistic exercises, researchers have recommended using mean velocity to estimate non-ballistic resistance exercise intensity and 1RM (Jidovtseff, Harris, Crielaard, & Cronin, 2011; Jovanovic & Flanagan, 2014; Lake et al., 2017; Sanchez-Medina & Gonzalez-Badillo, 2011). Therefore, strength and conditioning practitioners considering using this device should establish whether peak velocity will provide them with suitable information to help inform athlete monitoring. Additionally, strength and conditioning practitioners should consider the differences recorded between the PUSH Band™ 2.0 and motion capture in this study. While not statistically significant, the results of the least products regression revealed that the PUSH Band™ 2.0 overestimated peak and mean velocity by 5 and 10% respectively during bench press with 60% 1RM. With 90% 1RM, it underestimated peak velocity by 27% and overestimated mean velocity by 8%. These findings are important because they highlight the need for strength and conditioning practitioners to reconsider the values that have been presented to estimate changes in 1RM from velocity data recorded with sub-maximal loads (Gonzalez-Badillo & Sanchez-Medina, 2010). It may be possible to monitor training intensity and therefore indirectly track strength improvements with the valid measures of peak velocity presented by the PUSH Band™ 2.0 in the present study in accordance with the findings regarding their relationship with velocity change (Gonzalez-Badillo & Sanchez-Medina, 2010). However, additional research will be needed to confirm this. Additionally, it is possible that strength and conditioning practitioners may need to adjust these values relative to the load-velocity values provided by the PUSH Band^{TM} 2.0. This is because the mean velocity value recorded with 60% 1RM in the present study was considerably lower than that presented in the literature (0.608 (0.108) m/s vs. 0.80 (0.05) m/s) (Gonzalez-Badillo & Sanchez-Medina, 2010). However, with 90% 1RM, this difference is much less (0.329 (0.086) m/s vs. 0.339 (0.092) m/s).

While this study has provided some practically useful results, it is not without its limitations. First, we only considered two loads (60 and 90% 1RM). We selected these loads to provide data from relatively moderate and heavy bench press exercise, and because it has been shown that a 2-point load-velocity relationship can be used to accurately predict bench press 1RM (Garcia-Ramos et al., 2018). However, it might be useful to study the agreement between PUSH Band^{TM} 2.0 and motion capture peak and mean velocity data with lighter and intermediate loads. Second, we only considered peak and mean velocity. While the PUSH Band^{TM} 2.0 also provides peak and mean power data it was felt that because the velocity data underpins the power data that assessing agreement between the peak and velocity from both measurement techniques was the priority and would in turn have implications for power data obtained from the PUSH Band^{TM} 2.0 device, although this would require further research to confirm. We selected the bench press because of its popularity and because it provides a relatively simple barbell displacement. However, while we feel that the results of this study are practically useful for researchers and strength and conditioning practitioners, they should only be applied to the bench press. This is because the PUSH Band^{TM} 2.0 data processing is contingent on the resistance exercise that is being tested. Therefore, more research is required to assess agreement between the PUSH Band^{TM} 2.0 and gold standard methods, like motion capture, during other resistance exercises, including the back squat and variations of the Olympic weightlifts. Finally, it is possible that any differences between the motion capture and PUSH Band™ 2.0 peak and mean velocity data may have occurred because of differences in the way the data were filtered. For example, we applied what we considered the most robust method to our motion data. However, it is very likely that a completely different method was applied to the PUSH Band™ 2.0 data. The most obvious of these differences will be that typically signal noise is attenuated when numerically integrated (from acceleration to velocity). Additionally, PUSH Inc. have not made their filtering algorithms available. This should be considered when reviewing our results.

Conclusion

The results of this study show that during bench press exercise the PUSH Band 2.0™ provides reliable peak and mean velocity data. It also provides valid peak velocity data that is able to predict peak velocity from the gold standard motion capture method. However, it does not provide valid mean velocity data during bench press exercise. Therefore, we recommend that researchers and strength and conditioning practitioners can use bench press peak velocity data from the PUSH Band™ 2.0 confidently but should avoid considering mean velocity data from this version of the device. Additionally, we recommend that researchers and strength and conditioning practitioners should avoid using peak and mean velocity, from the PUSH Band™ 2.0 and from different devices, interchangeably. Finally, when comparing the results presented in different studies, researchers and strength and conditioning practitioners should be mindful that the values will differ based on the device/method that has been used.

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Table 1. Results of the motion capture reliability least products regression analysis.

	Peak velocity (60% 1RM)	Mean velocity (60% 1RM)	Peak velocity (90% 1RM)	Mean velocity (90% 1RM)
Slope	1.095	1.046	1.168	1.008
(95% CL)	(0.995, 1.196)	(0.858, 1.233)	(0.976, 1.360)	(0.910, 1.106)
Intercept	-0.059	-0.010	-0.036	0.016
(95% CL)	(-1.151, 0.032)	(-0.097, 0.078)	(-0.115, 0.043)	(-0.019, 0.050)

* CL = confidence limits.

Table 2. Results of the PUSH Band^{TM} reliability least products regression analysis.

	Peak velocity (60% 1RM)	Mean velocity (60% 1RM)	Peak velocity (90% 1RM)	Mean velocity (90% 1RM)
Slope	1.120	1.113	1.180	1.054
(95% CL)	(0.805, 1.434)	(0.827, 1.399)	(0.832, 1.528)	(0.874, 1.234)
Intercept	-0.103	-0.010	-0.078	-0.000
(95% CL)	(-0.364, 0.157)	(-0.097, 0.078)	(-0.260, 0.103)	(-0.069, 0.069)

* CL = confidence limits.

Table 3. Traditional measures of relative and absolute reliability for both measurement devices.

	Motion capture peak velocity 60% 1RM	Motion capture mean velocity 60% 1RM	Motion capture peak velocity 90% 1RM	Motion capture mean velocity 90% 1RM	PUSH Band peak velocity 60% 1RM	PUSH Band mean velocity 60% 1RM	PUSH Band peak velocity 90% 1RM	PUSH Band mean velocity 90% 1RM
ICC (95% CL)	0.984 (0.949, 0.995)	0.985 (0.953, 0.995)	0.985 (0.954, 0.995)	0.988 (0.961, 0.996)	0.947 (0.836, 0.983)	0.937 (0.804, 0.980)	0.957 (0.866, 0.986)	0.973 (0.917, 0.991)
CV (95% CL)	2.4 (1.0, 4.0)%	1.9 (0.05, 3.3)%	5.1 (3.1, 7.1)%	4.5 (1.8, 7.2)%	4.2 (1.2, 7,2)%	5.8 (1.7, 9.9)%	4.7 (2.3, 7.1)%	7.2 (3.3, 11.0)%

* ICC = intraclass correlation coefficient; CL = confidence limits; CV = coefficient of variation.

Table 4. Mean (SD) motion capture and PUSH Band™ peak and mean velocity and the mean (95% confidence limits [CL]) of the differences between them.

	60% 1RM		90% 1RM	
	Peak velocity (m/s)	Mean velocity (m/s)	Peak velocity (m/s)	Mean velocity (m/s)
Motion capture	0.786 (0.153)	0.543 (0.086)	0.441 (0.132)	0.297 (0.067)
PUSH Band	0.825 (0.168)	0.608 (0.108)	0.471 (0.135)	0.329 (0.086)
Mean difference (95% CL)	-0.039 (-5%) (-0.094, 0.017)	-0.065 (-12%) (-0.105, -0.024)*	-0.063 (-14%) (-0.106, -0.020)*	-0.038 (-13%) (-0.056, -0.019)*

* CL = confidence limits; if the 95% confidence interval does not include 0, then the difference is significant (*).

Table 5. Results of the method comparison least products regression analysis on peak and mean velocity.

	Peak velocity (60% 1RM)	Mean velocity (60% 1RM)	Peak velocity (90% 1RM)	Mean velocity (90% 1RM)
Slope	0.907	0.797	1.110	0.816
(95% CL)	(0.653, 1.161)	(0.657, 0.938)†	(0.792, 1.428)	(0.642, 0.990)†
Intercept	0.038	0.059	-0.118	0.025
(95% CL)	(-0.210, 0.286)	(-0.053, 0.170)	(-0.278, 0.042)	(-0.042, 0.092)

* CL = confidence limit; if the 95% confidence interval for the intercept does not include 0, then fixed bias is present; if the 95% confidence interval for the slope does not include 1.0, then proportional bias is present - † = proportional bias.