Short Communication

# Validity of wireless device measuring velocity of resistance exercises

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***Objectives***: The purpose of the study was to identify the level of accuracy in velocity measurement from a newly developed inertia sensor.

***Design and Methods***: Five subjects performed two dumbbell exercises for total of four sets of ten repetitions with a light intensity. Velocity data were taken and considered for analysis from two devices; the inertia sensor, wirelessly connected via Bluetooth™ to a smartphone, and a motion capture system. Both data were taken at the sampling frequency of 200 Hz. Identical data sets of peak and average velocity were analyzed with Pearson product-moment zero-order correlation using total 200 data points (5 subjects, 4 sets, and 10 repetitions) on both exercises with p value of 0.05. Data were also analyzed using the same statistical procedure for left and right side to ensure the device-device data consistency.

***Results***: Results showed high correlations in both exercises between the two velocity measurement methods (0.80 - 0.92), indicating the accuracy of the data from the inertia sensor is supportive. Left and right side correlations were also high from the inertia sensor (0.90 - 0.93) indicating that the data were similar with relatively identical movements between the two limbs.

***Conclusions***: With the accuracy of the velocity measurement, this would potentially replace currently used, wired devices to accommodate user-friendly, accessible to more exercises to measure velocity.

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**Key words**: wireless sensor ■ resistance training ■ measurement ■

## INTRODUCTION

Technology use in the sport industry to measure athletes' physical status has grown immensely. The use of Global Positioning Systems, accelerometers, and gyroscopes, used together and separately, are examples of wireless technology being used for the purpose of measuring performance or monitoring training.[1-2] For the general population, wireless fitness bands also have potentially useful capability for measuring daily activities. The growing popularity of these devices for athletes and the general population highlights the importance of understanding the information gained from wireless, real-time measurement of activity and training.

A newly developed inertia sensor (PUSH™, PUSH, Inc. Canada) is relatively economical, wearable wireless device, specifically designed for use during resistance training. The device is worn on the forearm, and provides an estimation of the movement of the barbell or dumbbell gripped with the hands. The inertia sensor provides immediate kinematic feedback about current performance of exercises supported within its software. Currently, the device displays average and peak values for velocity and power on the app with a smartphone or tablet. With competing technologies, measurements are taken using a wired device such as Tendo-unit (Tendo Sport machine, Slovak Republic) and GymAware (Kinetic Performance, Australia) in both laboratory and weight room environment.[3-5] While these wired devices have their importance, given a capability to provide immediate feedback, the fact that a wire or cord must run between the device and the bar may limit the exercises that can be measured. The wireless inertia sensor, transmitting via Bluetooth™, may provide useful measures in the training environment without the limitation of a connection to the bar, and without a hassle of bringing athletes to the laboratory for testing or data processing after the testing.

There are several considerations when new devices become available on the market. From a scientific standpoint, establishing the validity of the device is essential to ensure that the device is measuring what is intending to measure. A standard instrument to measure kinematic qualities of movement is three-dimensional (3D) motion capture hardware and software. As in past studies for validation purpose on kinetics and kinematics, different types of devices are being used,[6] but 3D motion capture system was deemed a satisfactory criterion measure to test that the PUSH™ device as it is capable of reporting accurate data with minimal errors. The device is relatively new and its data acquisition accuracy requires examination scientific examination in order to determine its reliability. Therefore, the purpose of the study was to measure accuracy (validity) with a laboratory-based test environment for two specific exercises. Specifically, the study was designed to validate velocity measurements taken with the wireless device

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compared with 3D motion analysis in both a linear and curvilinear exercise.

## METHODS

### Subjects

Five subjects (ranges of: age; 24-36 y/o, height; 166-182 cm, mass; 55-90 kg) volunteered to perform two exercises with two light intensities. The subject eligibility criteria included: reported being free of injuries, at least or over 18 years of age, and currently engaging in resistance training. Study information was provided to all individuals verbally prior to participation. The study protocol was approved by the University's Institutional Review Board, and all subjects signed informed consent form prior to participating the study.

### Data Collection Procedures

All subjects reported to a laboratory for this study. In order to display the inertia sensor data, the PUSH™ App (Apple, San Francisco, CA USA) was downloaded to smartphones. As the company claims that a sampling rate of the device is set at the fixed rate 200 Hz, all data were collected at the sampling frequency for all subjects trials. Two units (one on each forearm) were used to assure that the device is measuring similar data in a relatively identical motion of the chosen exercises. The device was attached to both forearms to compare the values between the left and right side. As the device is a relatively new product this step was necessary to assure the device-device consistency as well as to compare the data with the 3D motion capture data.

For the 3D motion capture, kinematic data were collected using motion capture video graphic and analog data acquisition system (Nexus 1.8.5, VICON, UK) with six cameras at a sampling rate of 200 Hz to match the same sampling frequency as the wireless inertia sensor. Reflective markers were placed bilaterally to make joints and segments of head, shoulder, upper arm, elbow, forearm, wrists, fingers, trunk, thigh, knee, shank, ankle, heel and toe using a Full Plug-in-gait marker set. Diameters of all reflective markers were 20 mm. The calibration volume was 5.5 m long, 5.2 m wide and 2.4 m high. All subjects were position in the center of calibration volume to assure all markers are visible by at least two cameras at all time during the data collection. For all subjects, X axis was determined as medial-lateral, Y axis was anterior-posterior, and Z axis was set as vertical. To minimize the error from the data collection during the 3D motion capture, minimal, tight clothing were provided to all subjects. Kinematic data were low pass filtered with a fourth Butterworth filter with cutoff frequencies of 15 Hz.[7]

All subjects performed 1) dumbbell (DB) biceps arm curl, and 2) DB shoulder press for total of 4 sets of 10 repetitions for each exercise. First 2 sets were done with 4.54 kg (10lb), and last two sets were done with 6.82 kg (15lb) in each arm to perform both exercises. Those two exercises were chosen to accommodate the two different movement characteristics (linear and curvilinear) for the validation purpose. The DB arm curl is a mostly 2-axis action with a combination of anterior-posterior and vertical movements and very minimal medial-lateral movement during the lift. The dumbbell shoulder press is a primarily vertical motion with some medial-lateral movement and minimal anterior-posterior movement throughout the lift.

### Data and Statistical Analysis

The company claims that although appropriate placement of the device is at proximal side of the forearm, the velocity data is primarily considered at the hand region where the external resistance is held. In order to validate the company's claim, the PUSH™ data was compared with the marker sets in the hand's coordinates.

All 5 subjects performed total 4 sets of 10 repetitions in both exercises, total 200 data points of average and peak velocity were considered for the correlation analyses. Although number of subjects was small, the number of data points being used for the correlation analysis for the device validation purpose seems appropriate.[8]

For the first analysis, left and right side measurements were analyzed using Pearson product-moment zero-order correlation to examine the relationship between the left and right sides of the PUSH™ data. As mentioned earlier, this data analysis is to assure that left and right sides are measuring the data similarly as a device-device consistency. Although this is not focus of the study, this also assured subjects' familiarity on correct movement of the chosen exercises. At the same time, left and right sides of the 3D motion analysis data was also analyzed in a same manner.

Devices on each arm were compared separately with values from the motion capture system, using paired t-tests and a Pearson product-moment zero-order correlation with 95% confidence interval. The analyses served to compare the relationship of values obtained for each device with the motion capture system. A Fisher's R to Z transformation and online calculator was used to compare the r-values between the wireless inertia sensor and the motion capture system for each arm.[9-10] If no difference in the relationship between the wireless inertia sensor and the motion capture system was observed between arms, data were pooled for further analysis.

Typical error, relative typical error, paired t-tests, a Pearson product-moment zero-order correlation with 95% confidence interval, visual inspection of the scatterplot, and linear regression were used to evaluate values obtained from the wireless inertia sensor and the criterion measure.[6,11] The criteria for statistical significance was set at $p$=0.05. Correlation values were interpreted according to scale developed by Hopkins: 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, and 0.9-1.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect.[12]

## RESULTS

For the arm curl, correlations for average velocity between left and right sides for the wireless inertia sensor was 0.90, and for the motion capture system was 0.99; for peak velocity between sides, it was 0.90 for the wireless inertia sensor and 0.98 for the motion capture system. For the DB shoulder press, correlations for average velocity between left and right sides

**Table 1** Comparison between devices using pooled left and right data for DB Shoulder Press

| | Average Velocity | Peak Velocity |
|---|---|---|
| Typical Error | 0.090 | 0.163 |
| Relative TE | 12.6% | 14.0% |
| Paired t-test p-value | 5.36995E-30 | 7.98159E-40 |
| Pearson's r | 0.864 | 0.801 |
| 95% CI for r | 0.834 - 0.888 | 0.761 - 0.836 |

**Table 2** Comparison between devices using pooled left and right data

| | Average Velocity | Peak Velocity |
|---|---|---|
| Typical Error | 0.060 | 0.105 |
| Relative TE | 7.2% | 6.5% |
| Paired t-test | 3.3842E-135 | 5.9521E-138 |
| Pearson's r | 0.883 | 0.923 |
| 95% CI for r | 0.859 - 0.903 | 0.907 - 0.936 |

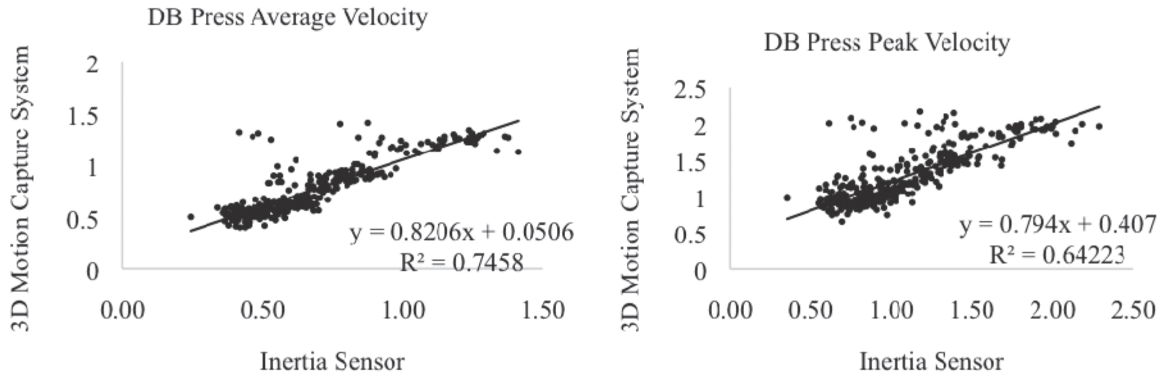


**Figure 1a,b** Scatterplot and linear regression equation for DB Press average and peak velocity

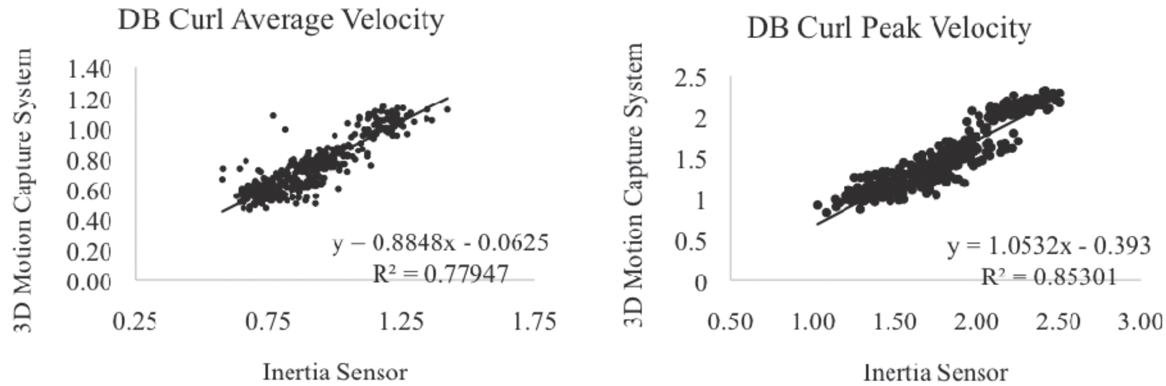


**Figure 2a,b** Scatterplot and linear regression equation for DB Curl average and peak velocity

for the wireless inertia sensor was 0.93 and for the motion capture system was 0.99; for peak velocity between sides, it was 0.93 for the wireless inertia sensor and 0.96 for the motion capture system. Correlations between devices for the left and right sides were not statistically different for arm curl peak velocity ($p$=0.689), arm curl average velocity ($p$=0.121), shoulder press peak velocity ($p$=0.117), and shoulder press average velocity ($p$=0.075). In light of the very large to nearly perfect correlations between left and right sides for each variable within each device, and the similar correlations between devices for each side, side data were pooled for later analysis.

Pooled data for DB Shoulder Press and for DB Arm Curl can be found in Tables 1 and 2, respectively. Scatterplots of average and peak velocity for both exercises can be found in Figures 1 and 2.

## DISCUSSION

The purpose of the study was to measure accuracy from the wireless inertia sensor using a 3D motion capture system from two exercises. The overall results supported the wireless inertia sensor to be an accurate measure of velocity data with fairly small errors when compared to the 3D data for the exercises tested. This indicates that the wireless inertia sensor is capable of measuring movement velocity in relatively slow movement during resistance training exercises. The figures above showed some outliers in several data points especially in peak velocity of DB shoulder press, but most of the 200 data points are within acceptable range of accuracy in both exercises. In addition, given the fact that the 3D data is a standard measure of 3D kinematics with correlation values ranging from 0.96 to 0.99

when left and right sides were considered, the wireless inertia sensor also showed a high correlation (0.90-0.93). This supports the two important factors from the current study; subjects are doing the exercise correctly by moving both sides similarly for both exercises, and the device detected the similar velocity pattern of both arms.

Unlike wired devices to measure velocities[3-5], the wireless inertia sensor is capable of measuring velocity and power of many DB exercises along with body weight exercises such as push-ups and jumps, or others like kettlebell swing, medicine ball throws, etc. Wired devices are only capable of tracking velocity and power from the exercises that are attachable to the bar. While wired devices' information is useful, it is ultimately limited due to the necessity of being attached to the bar. The wireless inertia sensor, on the other hand is capable of measuring a variety of exercises performed in the training room. Based on the information from the PUSH™ smartphone application during the current study, there are several practical applications that can be mentioned. While traditional approach of measuring training volume with sets, repetitions, and load is important, the device will collect all information within the smartphone application and organize the data simultaneously during a training session. The device can be a coach-friendly tool as it can be applicable to weight room environment without worrying about wires and limited exercise selection. The usefulness and potential application for athlete monitoring and training volume measures are expected based on the current study data.

The current study only examined the DB exercises in the upper body, thus the accuracy of other exercises is not predictable from the current data. DB exercises were tested to validate the device but this should not lead to assumption of measurement accuracy in other exercises, given that an algorithm is used to estimate bar movement, rather than simple displacement as used by GymAware and Tendo. Other types of exercises should be examined for the purpose of measurement validity such as differences in explosive exercises, like jumps and weightlifting variations. Furthermore, within- and between-session reliability should also be assessed in future studies, as it was not tested in this study. Lastly, between-device consistency should also be assessed, as the current study only evaluated two devices; future studies should consider testing multiple units for higher level of data accuracy.

In conclusion, measuring the peak and average velocity of the chosen exercises from the wireless inertia sensor seems accurate according to the 3D measures. If this finding holds true across other exercises, the wireless inertia sensor can be a good replacement of wired system on the market along with accessibility to a variety of other exercises.

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