

Article

A Novel Method for Estimating Throwing Speed in Handball using a Wearable Device

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Abstract: Understanding the shoulder-specific load in handball is important for both prevention and rehabilitation of shoulder injuries. The shoulder-specific load is largely a result of the number and speed of throws. However, it is difficult to quantify number and speed of throws in handball due to limitations in the current technology. Therefore, the purpose of this study was to develop a novel method to estimate throwing speed in handball using a low-cost accelerometer-based device. Nineteen experienced handball players each performed 25 throws of varying types while we measured the acceleration of the wrist using the accelerometer and the throwing speed using 3D motion capture. Using cross-validation, we developed four prediction models using combinations of the logarithm of the peak total acceleration, sex and throwing type as the predictor and the throwing speed as the outcome. We found that all models were well-calibrated (mean calibration of all models: 0.0 m/s, calibration slope range: 0.99-1.00) and precise ($R^2 = 0.71-0.85$, mean absolute error = 1.32-1.82 m/s). We conclude that the developed method appear to provide practitioners and researchers with a feasible and cheap method to estimate throwing speeds in handball.

Keywords: Accelerometer; throwing velocity; inertial measurement unit; throwing load; shoulder load

1. Introduction

The prevalence and incidence of shoulder problems are very high in handball [1]–[3]. In order to understand why and how such problems occur, it is required that causal pathways between exposures and outcomes are established [4]. Changes in training load are an example of an often-used exposure that is causally linked to injury development [5]. Following this line of thought, Møller et al. [1] showed that sudden increases in the number of hours spent playing handball is the primary driver of the development of shoulder problem. However, it seems likely that when investigating shoulder-specific problems, a more direct estimation of shoulder-specific load may lead to an increased understanding of why such problems occur.

Shoulder-specific load as opposed to training load in general, is a term used here to describe the overall loads of structures of the shoulder [4]. While a measure such as playing time can likely quantify training load in general, it is more speculative whether this is true for shoulder-specific load, as the number of throws is not just dependent on the playing time, but also the playing position [6]. Likewise, it seems biomechanically plausible that the throwing speed could have an effect on the shoulder-specific load. Although the kinetics of handball throwing has not yet been compared across different throwing speeds [7], a baseball study showed that the shoulder internal rotation torque increased with increasing throwing distance [8]. As such, there are indications that monitoring both number and speed of throws are important in order to obtain a good measure of shoulder-specific load.

Unfortunately, no feasible method to measure these parameters in a large cohort of players exists currently. Existing methods for measuring the number and speed of throws in general include

camera-based tracking methods and wearable devices. However, camera-based methods are typically both expensive and requires a multi-camera setup, and to our knowledge, no existing wearable device is validated in a handball setting. Nonetheless, given the low cost of wearable devices, such as accelerometers, it would be interesting to investigate the possibility of using accelerometers to determine the number and speed of throws in handball as well.

Measuring the number of throws and the speed of each throw are two separate problems. The former requires extracting the parts of a long recording of accelerations that contain a throw. The latter requires transforming the extracted parts into a single number representing the speed of the throw. In the present study, we are only concerned with attempting to solve the latter problem. Thus, the purpose of this study is to develop a novel accelerometer-based device that can estimate the speed of handball throws. We find that the suggested method is valid and well-calibrated, indicating that the method can be used to estimate throwing speed in handball.

2. Materials and Methods

Subjects

We recruited 19 experienced handball players (8 females, 11 males, age: 19 to 33 years, mass: 60.2-116.7 kg, height: 1.60-1.96 m, level of play ranging from amateur to professional) to participate in this cross-sectional study. Participants had to be at least 18 years old and not have experienced shoulder pain within the last month. The local research ethics committee waived the need for ethical approval and all participants provided informed consent prior to participating in the present study.

Methodology

All trials were performed in a biomechanical laboratory. Following a standardized warm-up, each participant performed a total of 25 throws using five different types of throws: (i) low-intensity standing throw without run-up, (ii) medium-intensity standing throw without run-up, (iii) maximum-intensity standing throw without run-up, (iv) maximum-intensity standing throw with run-up and (v) maximum-intensity jump throw with run-up. Each technique was used for five throws and the order of throws was randomised. For the low-, medium- and maximum-intensity standing throws without run-up, we asked the participants to emulate a short pass, a long pass and to throw as fast as possible, respectively.

During each throw, we recorded the position of the hand and the ball using 3D motion capture (8 cameras recording at 240 Hz; ProReflex MCU1000, Qualisys AB, Gothenburg, Sweden) using two reflective markers on the hand and the ball, respectively. Simultaneously, a custom-built device containing a triaxial accelerometer with a range of ± 200 g (ADXL377, Adafruit Industries, New York City, New York, United States) recorded the acceleration of the forearm at approximately 500 Hz. We placed the device in a wristband on the distal part of the forearm and secured it further using elastic band. The device recorded accelerations continuously throughout the entire session. After the session, we manually segmented the entire recording into parts containing only a single throw. We performed the segmentation by plotting the entire acceleration signal and locating the 25 peaks each corresponding to a throw. For each accelerometer segment, we calculated the peak total acceleration by taking the square root of the sum of the acceleration of each axis squared, i.e. finding the Euclidean norm. We obtained the throwing speed in a similar manner to previous handball studies [9], [10]. In short: Firstly, we low-pass filtered the marker positions using a two-way second order Butterworth filter with a cut-off frequency of 20 Hz. Secondly, we calculated the speed of the ball marker using a first-order forward difference. Thirdly and lastly, we identified the speed of the ball marker at the time of release, which we defined as the moment at which the distance between the ball marker and hand marker increased by more than 1 cm per frame.

Statistical Analysis

We developed four predictive models using multivariable linear regression. One model (Base) contained only the logarithm of the peak total acceleration as predictor, two two-variable models

further included throwing type (Type) and sex (Sex), respectively, and one model (Full) contained all three predictors.

We used 10-fold cross validation to estimate the internal validity of the predicted throwing speeds. Ten-fold cross validation entails splitting the data into 10 parts (folds), fitting a model to all folds except one and subsequently finding the difference between the observed and predicted speeds (i.e. the prediction error) of the fold that was left out. This procedure is then repeated until all folds have been left out once [11].

We assessed the overall predictive precision of the models by determining the R^2 statistic and mean absolute error in each hold-out fold. We assessed the ability of the models to produce unbiased prediction by assessing three levels of calibration as described by Van Calster et al. [12]: 1) mean calibration (calibration-in-the large), which is the difference between the mean predicted and the mean observed throwing speed. 2) Weak calibration (calibration slope) which is the tendency of the model to over- or underestimate the throwing speed, indicated by a calibration slope higher or lower than 1, respectively. 3) Moderate calibration (does the estimated throwing speed correspond to the observed throwing speed), assessed visually by plotting the estimated vs the observed throwing speeds. With good moderate calibration, points should be scattered around the identity line. Finally, we fitted all models to the entire dataset, to estimate model coefficients

Data and analysis code are available at <https://doi.org/10.17605/OSF.IO/YARFP>.

3. Results

We recorded 475 throws. Speeds of each type of throw are summarized in Table 1.

The Full model was the most precise model, followed by the Type model, the Sex model and finally the Base model (see Table 2). All models were well-calibrated, but the Type and Full models appeared to show slightly better moderate calibration than the Base and Sex models (see Table 2 and Figure 1). Models coefficients for all four models are summarized in Table 3.

Table 1. Summary of throwing speeds for the five different types of throws.

	Short pass	Long pass	Maximal intensity without run- up	Maximal intensity with run-up	Jump shot
Mean throwing speed (m/s)	13.8	15.8	21.0	22.5	20.9
Range of velocities (m/s)	[9.4; 23.4]	[11.8; 20.8]	[15.1; 25.9]	[14.6; 28.1]	[15.4; 26.8]

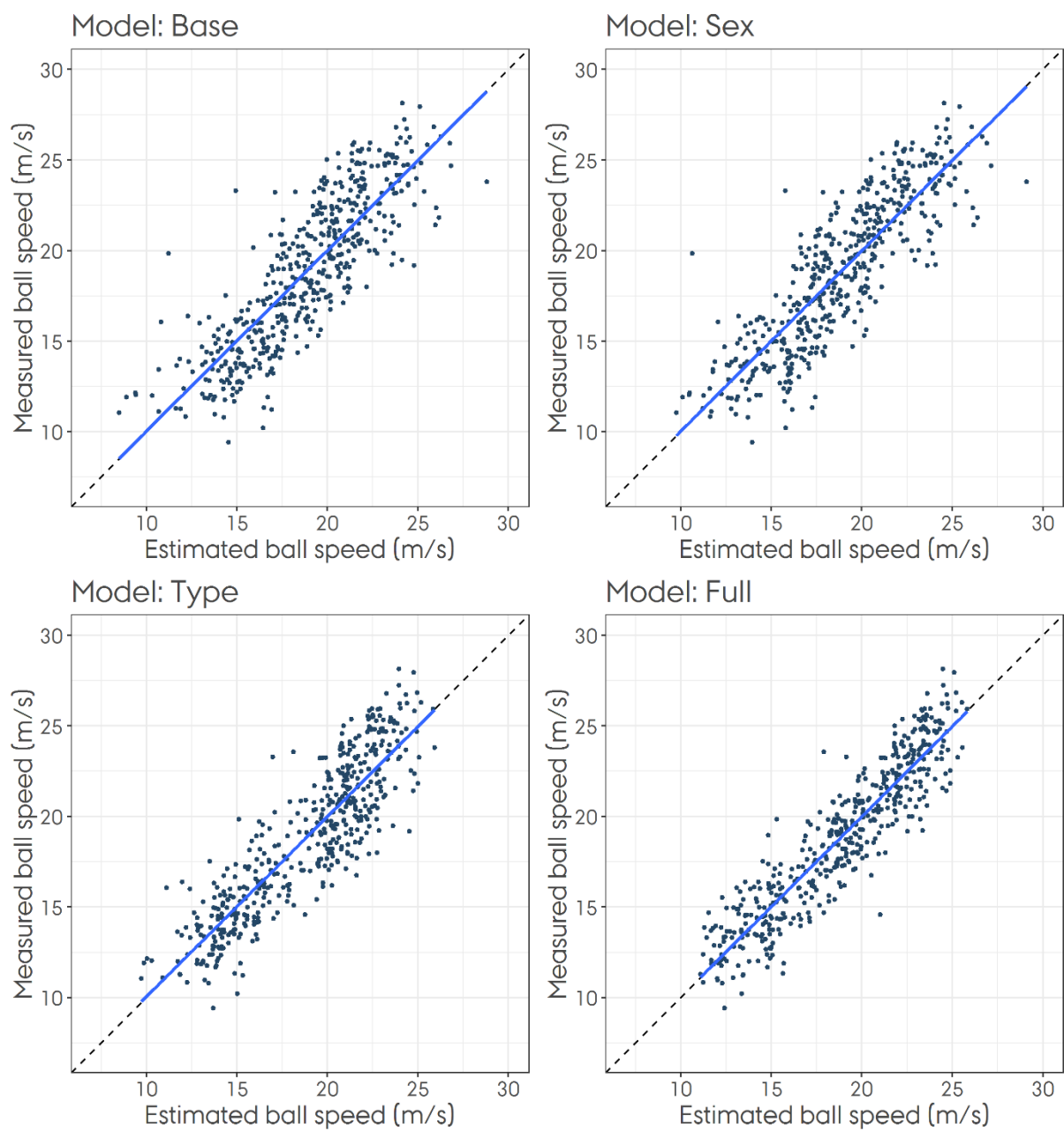


Figure 1. Calibration plots showing estimated vs observed speeds. The solid, blue line represents the calibration line and the dashed line (only visible at the ends of the solid line) represents a 45° line.

Table 2. Performance measures for all models. SD = Standard Deviation, MAE = Mean Absolute Error.

Measure	Model			
	Base	Sex	Type	Full
R ² (SD)	0.71 (0.03)	0.74 (0.05)	0.78 (0.05)	0.85 (0.03)
MAE (SD)	1.82 (0.16)	1.70 (0.17)	1.61 (0.14)	1.32 (0.12)
Weak calibration	1.00	1.00	0.99	1.00
Mean calibration	-5.6e-4	-6.2e-4	-1.5e-3	6.6e-4

Table 3. Estimated coefficient values for all models fitted to the entire dataset. CI = Confidence Interval.

Variable	Model			
	Base	Sex	Type	Full
	β coefficient (95%-CI)	β coefficient (95%-CI)	β coefficient (95%-CI)	β coefficient (95%-CI)
Intercept	-4.9 (-6.2 to -3.5)	-4.5 (-5.9 to -3.2)	4.9 (3.0 to 6.9)	8.1 (6.5 to 9.8)
log(Acceleration)	6.4 (6.0 to 6.8)	6.1 (5.7 to 6.4)	4.1 (3.6 to 4.6)	2.9 (2.5 to 3.4)
Sex (male)	--	1.5 (1.1 to 1.9)	--	2.3 (2.0 to 2.7)
Type (ref: Jump throw)				
Low intensity standing without run-up	--	--	-3.8 (-4.4 to -3.1)	-4.7 (5.3 to 4.1)
Medium intensity standing without run-up	--	--	-2.9 (-3.5 to -2.3)	-3.5 (-4.1 to -3.0)
Maximal intensity standing without run-up	--	--	-0.5 (-1.1 to 0.1)	-0.3 (-0.8 to 0.1)
Standing with run-up	--	--	0.5 (-0.1 to 1.0)	0.8 (0.3 to 1.3)

4. Discussion

The aim of this study was to develop a feasible and cheap method of estimating throwing speeds in handball. To this end, we developed four predictive models that all were well-calibrated, meaning that they produced unbiased estimates of the throwing speed, and precise, meaning that the estimate errors are small. Including sex and type of throw – both individually and in combination – appeared to increase the precision of the prediction models. As such, the proposed models shows promise for providing a valid method for estimating throwing speeds in handball.

While there were differences in precision between the models, the MAE of all of models were smaller than the measured speed differences between the low, medium and maximal (i.e. jump throws, standing throws with run-up and maximal intensity throws without run-up) throws. Similarly, Plummer et al. [13] found a difference between standing throws with 50 and 100% effort of 5 m/s on average and Wagner et al. [14] showed that the average difference in maximal throwing speed between elite and low-level players was 4.3 m/s. Thus, given the low MAEs, we believe that all

of the proposed models has sufficient precision to identify some of the important differences in throwing intensities and player abilities.

When developing prediction models with many predictors, there is always a risk of overfitting. We attempted to minimize the risk by using cross-validation to assess the internal validity, but it should be noted that cross-validation does not formally ensure that findings are externally valid [15]. Further, we deliberately aimed for a diverse set of participants and throwing conditions as previous research has shown that numerous biomechanical parameters depend on gender, level of play and the type of throw [7].

Compared to previous studies, the throwing speeds of the present study appear similar to those previously reported. For instance, we measured throwing speeds of the standing throw with run-up ranging from 14.6 to 28.1 m/s, while Wagner et al. [16] reported mean throwing speeds of 17.8 and 24.2 for low-level and elite players, respectively. Similarly, Wagner et al. [14] found that the mean throwing speed of the jump throw was 18.0 and 22.3 m/s for low-level and elite players, respectively, while we recorded throwing speeds ranging from 15.4 to 26.8 m/s for the jump throw.

Another important aspect of developing a method such as the present is whether the method is usable in practice. We chose to place the device in a regular wristband instead of affixing it more firmly using tape. As wristbands are standard equipment for many players, we believe players are more likely to wear the device in practices and matches than if we had used a custom-made packaging.

However, since the wristband was made of elastic weave, the accelerometer could move slightly relative to the forearm, which would introduce errors in the measured accelerations. Such relative movements are most likely to happen when the accelerations are high and thus we speculate that the prediction error is most likely to be high when the throwing speed is high. A speed-dependent prediction error could be a potential explanation for why we observed a non-normal distribution of the peak total accelerations and subsequently chose to log-transform the accelerations. By fixing the accelerometer more firmly to the forearm, it might be possible to minimize speed-dependent errors and thus provide a more accurate prediction of throwing speed.

The practical appeal of the presented method is substantial for both practitioners and researchers. For instance, monitoring the throwing speed might be a valuable asset for practitioners when employing a progressive return-to-throwing rehabilitation program following shoulder injury. Likewise, injury researchers obtain a feasible way of estimating throwing speeds during training and match, which can help elucidate the causal underpinnings of shoulder injuries.

When used in practices and matches, the accelerometer recordings would consist of long streams of data containing accelerations of many throws as well as of many other types of movement. Therefore, it is necessary to divide the stream of data into small segments containing only the recording of a single throw before estimating the throwing speed. In the present study, we manually segmented the entire stream of data, which was a relatively easy task given that each data stream only contained 25 throws clearly separated in time. However, when the data stream contains an unknown number of throws and when there is no clear separation between throws, manual segmentation becomes both time-consuming and potentially unreliable. Therefore, it is important to develop a method that can automatically segment a data stream into parts containing only a single throw before attempting to use the proposed method in settings where the boundaries between throws are not as clear. Furthermore, the models appeared to perform better when including throwing type. Therefore, another future direction for research is to investigate whether throwing type can be automatically discerned from the accelerometer recordings.

In conclusion, we developed four predictions models that can be used to estimate throwing speeds in handball based on a small, wrist-worn accelerometer. The models were well calibrated and precise, implying that the estimates were unbiased and errors were small. Thus, the present method might be a valuable future tool for both practitioners and researchers. However, future research is needed in order to also develop a method for obtaining the number of throws from the same device.

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