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Abstract

Purpose: Throwing loads are known to be closely related to injury risk, however for logistic reasons, typically only pitchers have their throws counted, and then only during innings. Accordingly, all other throws made are not counted, and therefore estimates of throws made by players may be inaccurately recorded and under-reported. A potential solution to this is the use of wearable microtechnology to automatically detect, quantify, and report pitch counts in baseball. This study investigated the accuracy of baseball pitching and throwing detection in both practice and competition using a commercially available wearable microtechnology unit. ***Methods:*** Seventeen elite youth baseball players (mean ± SD age 16.5 ± 0.8 years; height 184.1 ± 5.5 cm; mass 78.3 ± 7.7 kg) participated in this study. Participants performed pitching, fielding, and throwing events during practice and competition while wearing a microtechnology unit (MinimaxX S4, Catapult Innovations, Melbourne, Australia). Sensitivity and specificity of a pitching and throwing algorithm were determined by comparing automatic measures (i.e. microtechnology unit) with direct measures (i.e. manually recorded pitching counts). ***Results:*** The pitching and throwing algorithm was sensitive during both practice (100%) and competition (100%). Specificity was poorer during both practice (79.8%), and competition (74.4%). ***Conclusions:*** These findings demonstrate that the microtechnology unit is sensitive to detect pitching and throwing events, however further development of the pitching algorithm is required in order to accurately and consistently quantify throwing loads using microtechnology.

Key Words: GPS, Training, Competition, Workload Monitoring

Introduction

Baseball pitchers are reported to be at an increased risk of elbow and shoulder pain due to a combination of factors including but not limited to number of pitches thrown during a season, fatigue, height, and mass.[1,2] A significant association between the number of pitches thrown in both a game and during a season, and the increased incidence of elbow and shoulder pain has been reported in youth baseball pitchers.[3] It has been recommended that limitations should be placed on the total number of pitches per appearance, and per season in younger athletes.[2,4,5] Some authors report that higher pitch counts produced a significantly higher risk of elbow and shoulder pain,[2] while others found that pitchers who pitched > 3300 pitches in a season reported a decreased injury rate.[6]

At present, measurement of pitch counts is limited to counting the total number of pitches thrown.[2,3] Often during practice, individual players are responsible for manually counting the number of pitches to monitor the pitching load. This is less important during competition as pitch charts are kept regularly throughout game-play and coaches can refer to these for pitch counts. However, this method becomes limited during practice, as inaccuracies in athlete self-reporting and misreporting of total throwing load due to miscount or fatigue become a significant limitation.[7] Typically no counts are made of other throwing events that occur incidentally (e.g. during fielding practice) or as part of other warm-up or conditioning. In light of recent work highlighting the link between pitching loads and injury,[6] the importance of monitoring pitch counts during both practice and competition is paramount. We speculate that, as with other sporting activities, there is a relation between training/competition volume and performance/injury. With this in mind there is a clear need for a system that can both automatically and accurately monitor pitch counts during practice.

Wearable global positioning system (GPS) technology has been used extensively in team sport research to measure athlete workloads during both training and game-play.[9-11] Recently, the use of accelerometer and gyroscope technology, located within GPS units has been used to report the contact load experienced by athletes in collision sports.[12] Researchers have also explored the use of inertial measurement sensors, sampling at a frequency of ≥100 Hz, for the detection of a throwing action during bowling in cricket,[13] assessment of fast bowling technique in cricket,[14] automatic detection of balls bowled in cricket,[7] and three-dimensional measurement of the arm during the pitching motion in baseball.[15,16] All of these studies used tri-axial accelerometer and gyroscope technology to observe kinematic variables associated with bowling and pitching events. To date, no research has investigated the use of wearable microtechnology to automatically detect and quantify total throwing load in baseball. Consequently, the aim of this study was to validate the automatic detection of pitching and throwing events through the use of inertial measurement sensor technology.

Methods

Subjects

Seventeen elite youth baseball players from the Major League Baseball Australian Academy Program and the Queensland Bandits program (mean ± SD age 16.5 ± 0.8 years; height 184.1 ± 5.5 cm; mass 78.3 ± 7.7 kg) participated in this study. Subjects were recruited from the Australian Baseball Federation (ABF), who provided support and consent for the project. All participants received a clear explanation of the study, including information on the risks and benefits and written parental or guardian consent was obtained prior to participation. The Australian Catholic University Human Research Ethics Committee provided approval for this study (Approval Number 2014 34Q).

Design

In this observational, cohort study, throwing and pitching events were detected using commercially available wearable microtechnology units, and recorded manually by the researchers via notational analysis. Participants performed pitching, fielding, and throwing events during practice and competition while wearing a 10 Hz wearable microtechnology unit (MinimaxX S4, Catapult Innovations, Melbourne, Australia). The microtechnology unit (height 8.7 cm; width 4.4 cm; depth 1.8 cm; mass 67 gm) also housed a tri-axial accelerometer and gyroscope sampling at 100 Hz, to quantify three-dimensional accelerations and angular velocities, respectively. The microtechnology unit was located on the upper thoracic spine using a custom-made vest. The pitching and throwing algorithm was initially developed for automated pitch counting using accelerometer and gyroscope data from four pitchers, and further refined to differentiate between pitching and non-pitching events. Each pitch thrown provided reasonably predictable, repeatable, and consistent accelerometer and gyroscope data (Figure 1). Specifically, the algorithm examined both the accelerometer and gyroscope raw output for an angular velocity peak about the longitudinal axis to detect pitching events. Non-pitching events were measured by: (i) detection of a sequence of oscillations in the longitudinal axis during the fielding motion prior to a throw occurring, and (ii) a small angular velocity peak prior to a throw occurring. While any further technical details of the pitching detection algorithm are proprietary and have not been made available for publication, the present study is able to be replicated as the software is commercially available.

A true negative event was recorded when no pitching event was recorded either directly or via the microtechnology unit, and a movement event above the required threshold for the accelerometer and gyroscope data was recorded. Data was analyzed using software developed by the manufacturer of the microtechnology unit (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia). Since conducting the present study, a new model of the wearable microtechnology unit (MinimaxX S5, Catapult Innovations, Melbourne, Australia) has been released. The following methodology is still applicable with the new technology.

Methodology

The project was completed in three stages, and throughout the collection process, pitchers were given no instruction as to the velocity or type of pitches thrown throughout any part of the study.

Phase 1: Pitching Events. Participants performed their normal pitching routine with no instruction during a bullpen pitching session while fitted with a microtechnology unit. A total of 765 pitching events occurred during this phase of testing (mean ± SD trials per pitcher, 17.8 ± 3.3 trials; range 10 – 22 trials). Direct measures of pitch counts were completed in real-time by the researcher and verified through notational analysis of the practice vision. Additionally, all pitching events were recorded using a Casio Exilim EX-FH100 camera (Casio, Tokyo, Japan). This allowed cross-validation between the direct measures of pitch counts and automatic pitch counts obtained from the microtechnology unit.

Phase 2: Non-Pitching Events. Participants were then asked to perform a series of non-pitching events in random order to compare with the pitching events recorded during training and competition. These included: (i) fielding a ground ball hit from home plate and throwing the ball to first base (ii) throwing a pick off to first base, (iii) long-toss, and (iv) a base-to-base fielding drill. The non-pitching events were self-paced by participants, with recovery between events controlled by the participants (mean ± SD trials per pitcher, fielding a ground ball and throwing, 6.5 ± 1.0 trials, range 5 – 8 trials; throwing a pick-off, 8.3 ± 1.0 trials, range 7 – 11 trials; long-toss, 92.0 ± 1.0, range 91 – 93 trials; and a base-to-base fielding drill, 51.0 ± 10.0, range 41 – 61 trials). All non-pitching events were filmed for manual notational analysis and recorded by the microtechnology units to allow the detection of false positive events (i.e. detected a thrown pitch when the player did not throw a pitch).

Phase 3: Competition Events. Finally, participants threw a varied number of pitches during baseball competition. The total number of pitching events during this stage of testing was 293 (mean ± SD trials per pitcher, 38.3 ± 12.3 trials; range 16 – 51 trials). Direct measures of pitch counts during competition were completed in real-time by the researcher and verified through notational analysis. This allowed cross-validation between the direct measures of pitch counts and automatic pitch counts obtained from the microtechnology unit.

Statistical Analyses

To determine the accuracy of the pitching and throwing algorithm, the proportion of true-positive (i.e. detected a thrown pitch when the player threw the ball) and true-negative (i.e. no pitch detected when the player did not throw the ball) results were determined to allow the calculation of sensitivity and specificity values.[17,18] Further, the proportion of false-positive (i.e. detected a thrown pitch when the player did not throw the ball) and false negative (i.e. no pitch detected when the player threw the ball) results were also collected for the calculation of sensitivity and specificity values, along with positive and negative likelihood ratios with 95% confidence intervals (CI).[17,18] High sensitivity is required to detect throwing events using the microtechnology units, whereas high specificity is required to differentiate between various throwing and pitching events.[7] Standard criteria for evaluating sensitivity, specificity and likelihood ratios were used to enhance the real world application of these data.[19]

Results

A total of 923 events were recorded during all training phases (i.e. pitching and non-pitching activities). Of these, 765 were pitching events, with the microtechnology unit successfully recording each of these during training (100% sensitivity). Further, during all training phases the microtechnology unit displayed a specificity of 79.8% (Table 1).

Specifically, during bullpen training, 289 events were recorded with 231 of these true positives, 56 true negatives, and 2 false positives (100% sensitivity; 96.5% specificity). Similarly during long-toss, 276 true positives and 2 false positives were observed (100% sensitivity; specificity could not be calculated due to no true negative events). The non-pitching events recorded were: base-to-base fielding drill (100% sensitivity; 72.7% specificity), throwing pick-offs (100% sensitivity; 85.7% specificity), and fielding a bunt (100% sensitivity; 62.5% specificity).

*** Insert Table 1 Near Here***

During competition, there were a total of 332 events recorded by the microtechnology units, of which 293 of these were pitchers pitching a ball. The microtechnology unit displayed a 100% sensitivity during competition, successfully recording every pitch thrown. Further, the microtechnology unit displayed a 74.4% specificity during competition. Of the remaining 39 events, 29 were false pitches detected, and 10 true negative events where no pitch was thrown and no pitch was recorded (Table 2).

Insert Table 2 Near Here

Discussion

This study investigated the accuracy of pitching and throwing detection during both practice and competition using a commercially available wearable microtechnology unit (MinimaxX S4, Catapult Innovations, Melbourne, Australia). These results indicate that the microtechnology unit was highly sensitive for detecting pitching and throwing events during both practice and competition. However, the specificity of the microtechnology unit was poorer for detecting pitching and throwing events during practice and competition. Overall, the accuracy was 77.1% with the algorithm over-counting pitching and throwing events. These findings suggest that the microtechnology unit has excellent sensitivity for the automatic detection of pitching and throwing events during practice and competition, however needs further development to differentiate between pitching and throwing events during both practice and competition.

Sensitivity was high during both practice and competition, however there were reductions in specificity during the non-pitching events (i.e. a base-to-base fielding drill, and fielding a bunt). The pitching algorithm was designed to detect throw counts and to do so accurately, the algorithm was developed using data from multiple pitchers, and then tested on a cohort of new pitchers. High sensitivity is paramount in detecting pitching events using the microtechnology units in baseball, whereas high specificity is required to differentiate between pitching and non-pitching events. A high sensitivity score, as demonstrated in the findings of the present study, shows that the microtechnology units were able to automatically detect every pitch that occurred, which is a promising result. The lower specificity score found is likely due to the large proportion of random events (i.e. batting movements, warm up movements, resistance band movements, etc.) observed during practice and competition.

Specificity was lower than sensitivity during both practice and competition. This may be a result of the random nature of practice and competition, as there is likely to be an increase in the number of events which meet the criteria of a pitch being recorded by the microtechnology unit when no pitch was thrown. In future developments of this commercially-available processing software, a larger pool of accelerometer and gyroscope data will enable improvements in the algorithm filter to better discriminate between pitching and non-pitching events. It is possible that a wrist-mounted sensor, as opposed to a thorax-mounted microtechnology unit may provide more accurate automatic pitch counts. However, the development of a pitching algorithm developed with the use of this commercially available thorax-mounted microtechnology unit is advantageous because; 1) pitchers typically would not be willing to wear a wrist-mounted sensor on the pitching arm during practice and competition, and 2) pitchers are able to wear this microtechnology unit in a custom-vest under their uniform during both practice and competition.

Although this study is the first to investigate the novel automatic detection of pitching events using wearable thoracic-mounted microtechnology units, there are some limitations that warrant discussion. First, our study would have benefitted from a larger sample of players. Unfortunately, due to the nature of the sport of baseball in Australia, there is not a large pool of elite players from which to draw. To account for this limitation, we increased the number of trials each participant completed, although clearly, a larger study involving more players would strengthen the present findings. Second, it should be noted that the pitching algorithm was developed using accelerometer data from four senior pitchers and further refined using data from one senior pitcher. While a high sensitivity was observed, the poorer specificity demonstrates that further development is required before the unit could be recommended for routine use in baseball. Finally, no attempt was made to account for differences between youth and senior pitchers, and pitchers using different pitching technique. It has previously been shown that pitching mechanics differ between youth,[2] college,[20] and senior pitchers.[21] If the microtechnology unit was sensitive to detect differences in pitching mechanics, it is possible that this may have contributed to the high sensitivity and low specificity results of the algorithm.

Extending upon the present study by increasing the sample size and incorporating additional accelerometer and gyroscope data could improve the specificity of the pitching algorithm during both training and competition. Further, a pitching algorithm that can identify different types of pitches thrown, and estimate ball velocity, would be an invaluable tool for coaches and strength and conditioning staff. For the continued advancement and understanding of pitch count monitoring, further studies examining the automatic detection of pitching events in baseball are warranted.

Practical Applications

- A commercially available wearable microtechnology unit can automatically detect pitching events in both training (100% sensitivity) and competition (100% sensitivity).
- The automatic and accurate detection of pitching events with a wearable microtechnology unit will allow an enhanced understanding of pitching workloads during both training and competition.
- Given the increased importance of quantifying and understanding the workload-injury relationship, a tool that can automatically quantify pitching workloads during both training and competition is of value to coaches and strength and conditioning staff.

Conclusion

In conclusion, these results demonstrated that a wearable microtechnology unit was sensitive to detect pitching events during both practice and competition in a group of elite youth Australian baseball pitchers. However, specificity was lower during practice and competition due to a large number of false positives detected. While these findings demonstrate the potential of microtechnology within baseball, further development of the pitching algorithm is required in order to automatically, accurately, and consistently detect and discriminate between pitching and throwing events and to provide an accurate measurement of throwing workloads.

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Figure Captions

Figure 1. Example accelerometer data collected via a microtechnology unit (MinimaxX S4, Catapult Innovations, Melbourne, Australia) during ten pitching events.

Table 1. Accuracy of the wearable microtechnology unit for the automatic detection of pitching and throwing events during training.

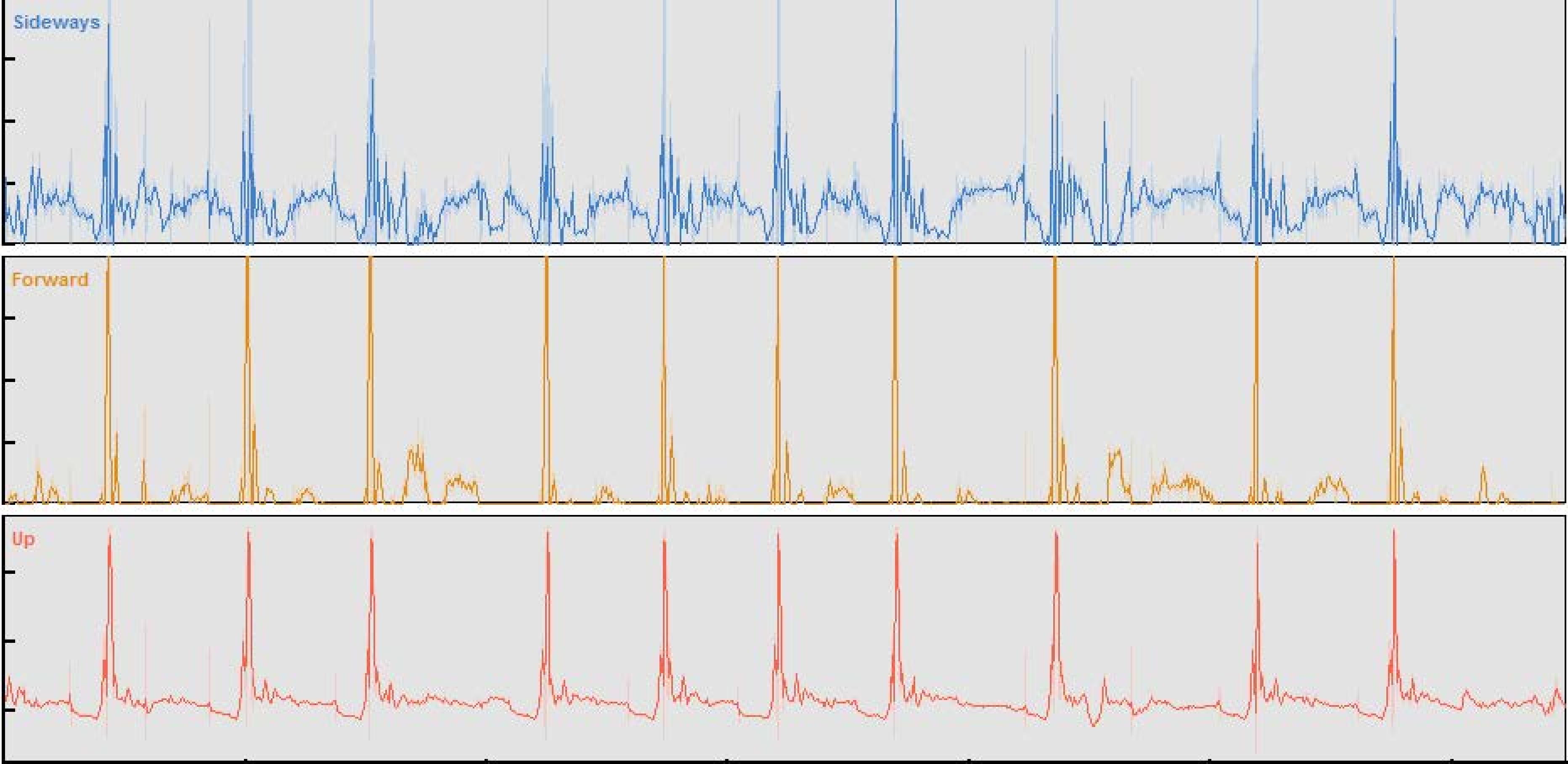
		Ball thrown during training	
		Ball Thrown	Ball Not Thrown
Automatic detection of throw	Throwing Event Automatically Detected	True Positive = 765	False Positive = 32
	Throwing Event Not Automatically Detected	False Negative = 0	True Negative = 126
	Total	Sensitivity = **100.0%**	Specificity = **79.8%**
	Likelihood Ratios	**Positive** Likelihood Ratio	**Negative** Likelihood Ratio
		4.94 (95% CI 3.62 to 6.73)	0

[1] A total of 765 pitching events were recorded during training

Table 2. Accuracy of the wearable microtechnology unit for the automatic detection of pitching and throwing events during competition.

		Ball thrown during competition	
		Ball Thrown	Ball Not Thrown
Automatic detection of throw	Throwing Event Automatically Detected	True Positive = 293	False Positive = 10
	Throwing Event Not Automatically Detected	False Negative = 0	True Negative = 29
	Total	Sensitivity = **100.0%**	Specificity = **74.4%**
	Likelihood Ratios	**Positive** Likelihood Ratio	**Negative** Likelihood Ratio
		3.90 (95% CI 2.29 to 6.66)	0

[1] A total of 293 pitching events were recorded during competition


Sideways
Forward
Up