THE RELATIONSHIP BETWEEN PEAK ACCELERATION OF BAT AND HAND PAIN IN BASEBALL PLAYERS DURING BASEBALL HITTING

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The purpose of this study was to investigate the relationship between peak acceleration of the knob of the bat and hand pain during baseball hitting. Eighteen college baseball players hit the ball on the tee with three bat locations. The players' hand pain sensation and the acceleration signals of the knob of the bat were collected. Hand pain was rated on a scale of 0-10 (0 for no sensation, incrementally up to 10 for maximum pain). The absolute peak accelerations were extracted. Results showed that the absolute peak accelerations of each axis at the frequency of the second bending mode (bandpass filtering at 350-750Hz) were strongly correlated with hand pain (ρ = 0.79–0.85, p < 0.05). In conclusion, the peak acceleration on the knob of the bat at the frequency of the second bending mode of the baseball bat exhibits a strong correlation with hand pain. It could be utilized as a wearable indicator to monitor baseball hitting impact in the future.

KEYWORDS: accelerometer, batting impact, vibration, pain, hook of hamate fracture

INTRODUCTION: Baseball hitting frequently leads to injuries in the hands and wrists (Nicholls et al., 2004). According to statistics from Major League Baseball (MLB) in the United States for the seasons 2011-2016, a total of 6,226 players from the major and minor leagues missed games due to hand injuries (72%) or wrist injuries (28%) (Rhee et al., 2021). The primary factor causing these injuries was hitting (40%), followed by fielding (30%) (Rhee et al., 2021). Batters usually experience pain or numbness in their hands due to the intense vibrations generated by the impact between the ball and the bat (Noble & Walker, 1994). Poor hitting positions often occur during both training and actual games. When the ball and the bat collide in an unfavourable position, the resulting intense vibrations can cause a tingling or numbness sensation in the hands. Prolonged exposure of the hand to high-intensity vibrations result in damage to the hand's bones, muscles, and nerves (Cutini et al., 2017; Koestler, 2010). The sensation of pain in the hands serves as an early warning indicator for impending injuries (Cutini et al., 2017; Koestler, 2010).

The bat's bending model can be primarily divided into the first, second, and third bending modes. Under the second bending mode, there are two antinodes and three nodes, with a frequency range of approximately 350-750 Hz (Russel, 2017). Previous research has shown that, under the second bending mode, the antinode near the base of the bat (approximately 15-20 cm from the knob of bat) is close to the location where players grip the bat, and it is also the area where players most commonly feel tingling (Russel, 2017; Sutton & Sherwood, 2010). Therefore, the high-frequency vibration signals under the second bending mode may be highly correlated with the sensation of hand pain. The purpose of this study was to investigate the relationship between peak acceleration of the knob of bat and sensation of hand pain through the aforementioned signal processing methods. This will help establish a wearable hitting impact indicator. We assumed that, after bandpass filtering from 350 to 750 Hz, the peak values of the acceleration signals from the knob of the bat will exhibit a strong correlation with the sensation of hand pain, serving as hitting impact indicators.

METHODS:

Participants: Eighteen college baseball players (Height: 179.5 ± 3.7 cm, Weight: 77.3 ± 10.5 kg, Years of playing: 9.5 ± 1.1) participated in the study. All players had not experienced significant bone or muscle injuries in the year before experiment.

Instrumentation: A maple wood baseball bat was used in this study. Prior to the experiment, two inertial measurement units (IMUs) (Vicon Blue Trident, UK) were attached to the knob of bat using elastic tape for secure fastening. The IMU 's measurement ranges are ± 200g for accelerometers. Data collection was conducted at a sampling rate of 1600Hz. The three-axis orientations are illustrated in Figure 1, which depicts the orientations measured by the IMUs attached to the knob of the bat.

Figure 1: Bat-ball impact position and IMU placement

Procedures: Before formal experiment, each participant engaged in a standardized 20-minute team warm-up routine. This warm-up consisted of overall body activities, starting with a 10-minute slow jog, followed by dynamic stretching and batting exercises. This familiarization with the batting experiment process was included as one of the warm-up activities. After participants completed all self-selected preparations, the batting experiment commenced. Each participant took swings to hit the stationary balls placed on a tee at three different locations of the bat in a random order. The hitting areas included one sweet spot (14 to 16 cm from the bat's top) and two non-sweet spot locations (3 to 5 cm and 34 to 36 cm from the bat's top) (Figure 1). The hitting area of sweet spot was based on previous research suggesting that the sweet spot of a bat is approximately 15.24 cm (6 inches) from the end of the barrel (Bahill et al., 2018), within an area roughly 3 cm long (Cross, 1998). A high-speed camera (recorded at 240 fps in slow-motion mode) was used to confirm whether the bat contacted the specified area at the moment of impact. If the specified area was not hit, the swing was considered a failure, and each location had to be hit 10 times, totaling 30 balls. A three-minute interval was arranged between each hitting. During the rest periods, participants were asked about any discomfort or pain in their hands, and their responses were recorded through a questionnaire. The participants rated the sensation of pain for each swing on a scale from 0 to 10, where 0 indicates no sensation, and higher numbers represent increasing levels of hand pain, with 10 being the most painful (Noble and Walker, 1994).

Data Processing: Three filtering processes were applied to the IMU signals. These included no filtering (raw data), bandpass filter 100-200Hz, and bandpass filter 350-750Hz (Russel, 2017). The peak resultant acceleration (PRA), peak absolute acceleration in the X-axis (PAAX), peak absolute acceleration in the Y-axis (PAAY), and peak absolute acceleration in the Z-axis (PAAZ) were analysed.

Statistical Analysis: All statistical analyses were conducted using IBM SPSS Statistics (version 23.0; IBM Corporation, Armonk, NY, USA). The Spearman's rho (ρ) tests were employed to assess the relationship between peak accelerations and hand pains. Correlation magnitudes were evaluated based on the following criteria: negligible: 0-0.09, weak: 0.10-0.39, moderate: 0.40-0.69, strong: 0.70-0.89, very strong: 0.91-1.00 (Schober et al., 2018). Statistical significance was set at α = 0.05.

RESULTS: The results revealed negligible to weak correlations between all peak accelerations analysed with unfiltered and with bandpass filtering at 100-200Hz (first bending mode) and hand pain sensation (ρ < 0.4, Table 1). However, when using a filter set at 350 to 750 Hz (second bending mode), moderate to strong correlations were found between all peak accelerations and hand pain sensation (ρ = 0.79–0.85, p < .05). Additionally, the peak absolute accelerations in the X-axis showed higher correlation with pain sensation in both hands (ρ = 0.84–0.85, p < .05).

Table 1: The Spearman (ρ) correlation coefficient between peak accelerations with different filter methods and hand pain.

Filtering processes	Parameters	Top-hand pain	Knob-hand pain
Unfiltered	Knob PRA	.263**	.345**
	Knob PAAX	.081	.083
	Knob PAAY	.366**	.396**
	Knob PAAZ	.226**	.240**
First bending mode	Knob PRA	.213**	.263**
	Knob PAAX	-.044	-.036
	Knob PAAY	.313**	.350**
	Knob PAAZ	.205**	.251**
Second bending mode	Knob PRA	.839**	.815**
	Knob PAAX	.841**	.849**
	Knob PAAY	.808**	.794**
	Knob PAAZ	.826**	.823**

Note: p<.05*; p<.01**; PRA = Peak resultant acceleration; PAAX = peak absolute acceleration in the x-axis; PAAY = peak absolute acceleration in the y-axis; PAAZ = peak absolute acceleration in the z-axis.

DISCUSSION: The main findings of this study were that all peak acceleration parameters in the second bending mode exhibited strong correlations (ρ = 0.79–0.85) with perceived pain in both hands. In overall, the peak acceleration values along the anterior-posterior axis (i.e. x-axis, which represents the direction of bat-ball impact) demonstrated higher correlations (ρ = 0.84–0.85) compared to other axes.

This study indicated that significant correlations with hand pain were only observed in peak acceleration in the second bending mode (Table 1). These results suggest that, for objective quantification of hand pain, the acceleration signals collected from the knob of the bat should be filtered using a bandpass filter in the range of 350 to 750 Hz to observe the vibration of the second bending mode of the bat. This finding validates our research hypothesis, as hands are most sensitive to frequencies in the range of 350-750 Hz (Russel, 2017). The second bending mode has three nodes and two antinodes on the bat. One of the two antinodes is near the knob of the bat, appearing at a distance of 14 cm from the bat's bottom, which is also the location of the grip and the area where the hands are most susceptible to pain (Russel, 2017; Russell, 1999; Sutton & Sherwood, 2010).

Long-term exposure to high-intensity vibrations can lead to damage to the bones, muscles, and nerves in the hands (Cutini et al., 2017; Koestler, 2010). Previous research on hand pain in cricket players has indicated a correlation between hand injuries and reduced training or playing time. Most players with hand pain in the past month experienced hand injuries (Shah et al., 2020). Therefore, it is suggested that hand pain may be associated with sports injuries. In our research methodology, we recorded the hand pain of batters at the moment of batting. Based on the results of this study, we identified a potential method for assessing the risk of hand injuries and hitting impact.

CONCLUSION: This study found the strong correlations between the peak accelerations of the knob of the bat in the frequency of the second bending mode and the sensation of hand pain. Additionally, the anterior-posterior axis reflecting the direction of bat-ball impact exhibits a higher correlation. The peak acceleration in anterior-posterior axis may be considered for the development of a hitting impact indicator. The results of this study can assist in monitoring the impact on the hands during baseball hitting, serving as an observed indicator for preventing sports-related hand injuries in the future.

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