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Review Article

Competitive Baseball Pitchers' Use of Wearable Technology

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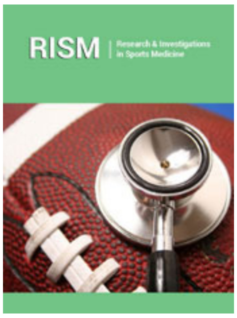

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Abstract

Baseball pitching involves the fastest recorded movement of a human body segment, with the upper extremity rotating around the glenohumeral joint at a rate of over 7,000°/second. On average, roughly 116,000 shoulder injuries are sustained by high school athletes each year. Of these, approximately 39% are musculoskeletal strains and sprains. Multiple risk factors have been explored when studying elbow and shoulder injuries in pitchers. These factors include, but are not limited to, the number of pitches thrown during a season, fatigue, height, and mass. Although steps have been taken to mandate rest days and maximum pitch counts, elbow and shoulder injuries continue to increase among pitchers. This indicates that there may be other factors leading to elbow and shoulder injuries in pitchers besides the in-game workload. As such, means of better quantifying motions during practice and competition are valuable for reducing the risks to pitchers' elbows and shoulders. Wearable Inertial Measurement Units (IMUs) record lower measurements compared to marker-based motion capture for assessing shoulder rotation speed, elbow varus torque, and arm slot when pitching. However, these devices have been shown to be reliable in their measurements. This reliability justifies IMUs' place in clinical and research applications for describing the demands and workload of pitching. Nevertheless, coaches, clinicians, and researchers should be mindful that the measurements from currently available IMUs may be less accurate than marker-based motion capture.

Introduction

Baseball pitching involves the fastest recorded movement of a human body segment, with the upper extremity rotating around the glenohumeral joint at a rate of more than 7,000°/second [1]. The forces produced with this movement increase both ligamentous and musculoskeletal damage and have been associated with repeated micro trauma sustained by the elbow and shoulder during the demands of pitching [2,3]. Considering the rate of speed, high volume, intensity, and frequency of pitching, it is unsurprising that elbow and shoulder injuries among pitchers are a concern for athletes and sports medicine clinicians [4-8]. On average, roughly 116,000 shoulder injuries are sustained by high school athletes each year [8]. Of these, approximately 39% are musculoskeletal strains and sprains [8]. Despite efforts to address elbow and shoulder injuries by monitoring maximum pitch counts and mandating rest days, the rate of elbow and shoulder injuries among pitchers at all levels continues to rise [4-8].

When pitchers reach elite college and professional levels, injury is accompanied by the risk of loss of future earnings and financial compensation. The financial impact of surgical treatments on injured pitchers can become a concern to the athlete, especially when future compensation is affected [9]. In addition to monetary concerns, surgery and long-term rehabilitation have potential adverse effects on the throwing mechanics of pitching [10]. Changes to an athlete's previously successful mechanics may diminish performance [10]. All these factors have the potential to decrease quality of life for pitchers following shoulder and elbow injuries [11]. Thus, mitigating the risk of injury, surgery, and long-term care is of utmost importance for pitchers.

Multiple risk factors have been explored when studying elbow and shoulder injuries in pitchers. These factors include, but are not limited to, the number of pitches thrown during a season, fatigue, height, and mass [12,13]. However, the accurate measurement of these risk factors is not consistently applied. For instance, youth baseball has limited pitch counts during games, yet the counts do not include throws during practice [8,14,15]. Measuring pitch count and workload during practice becomes difficult and often relies on self-reporting [15]. In recent years, wearable technology has been proposed as a method for monitoring daily motions and energy expenditure during practice. Therefore, the purpose of this review is to describe the available wearable technology used for motion analysis in baseball.

Motion Analysis

In the field of injury prevention, diagnosis, and management, the role of motion analysis has been well described [16-22]. Motion analysis has been used to assess gait [16], outcomes of arthroplasty [16,17], and the impact of conditions such as Parkinson's disease and cerebral palsy on activities of daily living [18,19]. In addition to playing a role in the general population, motion analysis has been used to describe the motions involved in various sports [20-22]. Until recently, most analysis used marker-based motion capture and video analysis [23-25]. Although marker-based motion capture is considered the gold standard for motion analysis, it is not without limitations. It can be time-consuming to set up and calibrate a camera-based tracking system [25]. These systems also may be affected by visual artifacts, occlusion, and shifting background light [25]. Most baseball teams conduct practices and competitions outdoors. This makes marker-based motion capture impractical for clinical use in many cases. Combined with the fact that these systems can often be expensive, there has been a growing market for cost-effective, more compact, and wearable motion analysis technology.

Global Positioning Systems

Global Positioning System (GPS) devices were developed based on the work of the 1944 Nobel laureate in physics, Isidor Rabi. Global positioning relies on radio signals transmitted between a satellite and a receiver [26,27]. This relay of signals provides information about the distance between the receiver and the satellite [28]. When four or more satellites are incorporated, the accurate location of the receiver can be triangulated. GPS devices have become increasingly popular for sports motion analysis [29], used by coaches, sports medicine clinicians, and sports performance coaches to assess the physical demands placed on athletes participating in team sports [29]. The activity profile gained from the use of GPS devices includes total distance traveled and velocity [30]. This information can be used to determine the rate of fatigue and the periods of most intense physical activity during practice and competition [30]. Many GPS units available on the commercial market now contain Inertial Measurement Units (IMUs) [31,32].

Inertial Measurement Units

Inertial measurement units were originally used in aircraft navigation in the 1930s [33]. Initially, these devices were large, costly, and consumed excessive power [34]. These constraints restricted the use of IMUs to large-scale applications [34]. With recent trends in the miniaturization of electronic devices and improved efficiency in production, IMUs are now incorporated into devices such as smart phones and GPS devices [34]. Using accelerometers and gyroscopes, IMUs are able to provide information about movements, including acceleration, angular velocity, and rotation [29,35]. Considering the vast amount of motion analysis data that can be provided through the use of IMUs, many devices are paired with software that uses predetermined algorithms to determine such values as workload and torque at specific joints [36]. The inclusion of this software removes a time-consuming component of clinical research. These IMUs also overcome some of the limitations of video-based motion capture, including visual distortions and changes in light [25]. Removing these limitations makes IMUs more practical for use during outdoor practice and research conducted outside the laboratory setting.

Although IMUs have a relatively short history of use in motion analysis, relevant studies date back to the 1970s [37]; they have been used in the healthcare field for more than two decades. Previous research has described the use of IMUs to detect movement and sleep patterns in the general population [38], and they have also been validated for use in analyzing motions, including running, swimming, and jumping [39-41]. The ability to collect data such as these highlights the applications for IMUs in the field of sports medicine and research. To collect data through the most noninvasive means, the devices must be designed in a manner that is not restrictive to the motion being assessed. For instance, goniometers and exoskeletons entail at least some level of constraint to the joint being measured [42,43]. This has led to the development of garments containing either embedded or housed sensors for motion analysis [44,45].

Wearable Technology

In recent history, nearly all forms of sensors have grown smaller in size and more affordable. These developments have been crucial to the integration of sensors into nearly all aspects of life. Interestingly, this progress was predicted more than three decades ago by Ubiquitous Computing [46].

Through these advances, both wired and wireless wearable IMUs have become commercially available over the past decade [47-51]. In addition to consumer-based markets, these smaller, more affordable IMUs have also become commonplace in research [52-55]. For instance, wearable IMUs have been used in studies examining the biomechanics of physical activity, such as golf and dancing [54,55]. However, most of this research has been conducted on non-ballistic movements [56]. It has been predicted that, as time progresses, wearable IMUs will grow in popularity in both clinical and research fields [25,56].

Use of Wearable Inertial Measurement Units in Baseball

Inertial measurement units have increased in popularity and are marketed to baseball players as a tool to enhance performance and aid in rehabilitation [49]. By and large, the players presumed to receive the greatest benefit from the use of wearable IMU's are pitchers [57]. In addition to their use for performance enhancement and injury rehabilitation, wearable IMUs have grown in popularity in clinical research on baseball players [25,58-65]. New IMU devices are constantly being developed, and research has proliferated with the aim of gathering even more information about baseball pitching through the use of wearable technology [15,66].

As more IMU devices come on the open market, researchers are attempting to validate them in comparison with marker-based motion capture during pitching. Prior to the increased use of IMU devices, the gold standard for motion analysis was marker-based motion capture [24,25]. The use of wearable sensors is advantageous for multiple reasons. As mentioned above, marker-based motion capture can be time consuming and expensive, while also requiring additional time for video inspection [25]. These impediments have further emphasized the need to validate wearable IMU devices for accurate motion detection.

Some research has shown that wearable IMU devices, specifically the Driveline PULSE (Driveline, Kent, WA), show significant correlation with marker-based motion capture for the measurement of shoulder rotation speed, elbow varus torque, and arm slot [62,63]. However, other studies have called into question the accuracy of the Driveline PULSE when compared to marker-based motion systems [67]. These studies have shown that the Driveline PULSE produces lower measures of shoulder rotation speed, elbow varus torque, and arm slot than those recorded using marker-based motion systems [67]. Fortunately, all studies attempting to validate the Driveline PULSE have agreed that the device is consistent in measuring shoulder rotation speed, elbow varus torque, and arm slot [62,63,67]. Therefore, although measures from the Driveline PULSE may be lower than those reported by marker-based motion capture, the device is reliable, particularly from an intrapersonal perspective [67].

This reliability among pitchers makes a wearable IMU a valuable tool for clinical research. This has been demonstrated by studies showing that elbow varus torque is lower when pitching from a regulation pitching mound compared to flat ground [60,61]. The previously cited studies also found that pitching shorter distances did not result in a significant decrease in elbow varus torque [60,61]. Additionally, increased ball weight was found to correlate with greater medial elbow torque [64]. The use of wearable IMUs suggests that torque at the medial elbow is higher with fastballs compared to curveballs [68].

Discussion

In this review, we describe the available wearable technology used for motion analysis in baseball. Pitching in the sport of baseball entails the fastest motion of a human joint ever recorded [1]. Given the high intensity and repetitive nature of this motion, identifying and mitigating risk factors is crucial. Although steps have been taken to mandate rest days and enforce maximum pitch counts, elbow and shoulder injuries continue to increase in incidence among pitchers [4-8]. This seems to indicate that there are other factors leading to elbow and shoulder injuries in pitchers besides game workload. The number of pitches thrown, fatigue, height, and mass have all been implicated as predisposing factors for elbow and shoulder injury [12,13]. However, this does not consider other important factors, such as throws during practice [15]. As such, means of better quantifying the motions during practice and competition are valuable for reducing the risk of elbow and shoulder injuries in pitchers.

In recent years, technology has advanced to the point of creating smaller and more affordable wearable IMUs that are readily accessible on the commercial market [52-55]. These wearable IMUs have overcome some of the limitations encountered when using video-based and more restrictive devices [22,42,43], but the models available are known to be less accurate than marker-based motion capture [67]. Despite producing potentially lower values than marker-based motion capture, IMUs have been found to be consistent in their measurements [62,63,67]. This reliability justifies IMUs' place in clinical and research applications for assessing the demands and workload of pitching [60,61,64,68]. Nevertheless, coaches, clinicians, and researchers should be mindful that the measurements from currently available IMUs may be less valid than marker-based motion capture.

Conclusion

The currently available evidence suggests that wearable technology can play an integral role in both clinical and research applications in baseball. Those using wearable technology to quantify and assess the motions in baseball should be mindful of the limitations of any device being used. Further research should focus on improving the validity of wearable IMUs and determining the most appropriate applications for these devices.

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