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OVERVIEW
1. Pitching
2. Sprinting
3. Jumping
4. Technological integration
    a. Force Plate Analysis
    b. Motion Capture
    c. Accelerometry/GPS
    d. Inertial Measurement Unit
5. Limitations of Technology
6. Utilization of Data

1) **Pitching-** Baseball pitching is considered one of the most aggressive throwing actions produced by athletes. Dillman et al. (1993) provided detailed kinematic information on the shoulder during pitching and concluded, "throwing a baseball at maximal velocity is one of the most highly dynamic skills in all sports." The violent and repetitive nature of pitching has historically resulted in a high incidence of elbow and/or shoulder injury among pitchers; this trend has only continued in recent years [1-5]. Upper extremity injuries in baseball typically require the longest timeline of recovery, and account for approximately 40% of injuries in baseball [31]. Practitioners and researchers alike have sought to investigate pitching biomechanics to better implement preventative and rehabilitative training programs to reduce the rate of injury [1]. Focus has been paid to valgus stress of medial elbow tissues and resultant injuries to the ulnar collateral ligament (UCL) [2-4]. Werner et al. (1993) conducted the first study simultaneously assessing and correlating joint kinematics (i.e., range of motion and joint velocities), joint kinetics (i.e., joint forces and torques), and muscle activity at the elbow during pitching [1]. Research surrounding this topic has evolved significantly since this publication, providing likely mechanisms of injury and specific recommendations to prevent or reduce the risk of medial elbow injury [3-4]. Consensus opinion suggests the principle mechanism of medial elbow injury is inadequate regulation of a valgus moment, often between 20 and 120deg. flexion [6-8].

2) **Sprinting-** Acceleration, deceleration, agility and change of direction (COD) are essential characteristics of an effective baseball player [13]. Due to the nature of the sport, a vast majority of sprinting in baseball occurs within initial and transitional phases of acceleration [9], and thus, biomechanical principles related to these phases are most relevant. Sprinting is a skill that requires highly developed neuromuscular characteristics (e.g., rate-coding, neural drive, intra/inter-muscular coordination, etc.) utilized and oriented in the proper vector [10]. In other words, proficiency in sprinting is the product of superior strength and power abilities paired with the ability to execute within the domain of the sport. Within the context

of baseball, athletes rarely achieve maximal velocities due to curvilinear baserunning or context-dependent reaction to gameplay (i.e. out-fielding) [13]. Verkhoshansky (1996) drew a comparison between quickness and high velocity sprinting, defining quickness as “a rapid movement entailing little resistance or muscular effort” [11]. Likewise, COD and agility demands may differ from linear sprinting in angle and velocity, potentially impacting technical execution, deceleration, reacceleration, knee joint loading, and lower limb muscle activity [12]. These differences may be overlooked in athletic development of the baseball player, potentially provoking lower extremity injury. The most common injury in sprinting is hamstring strains [14,15]. Within baseball, some studies indicate lower extremity injuries account for approximately 60% of injuries [31]. A proposed mechanism of hamstring injury in sprinting is the active lengthening of the hamstring in the terminal swing and early stance phase [16,17]. Coaches should carefully implement training methods and exercises which correspond to the biomechanical demands of the sport to reduce the rate of lower extremity injury [18-19].

3) **Jumping-** Jumping is an essential movement pattern to sport, including baseball. Jumping proficiency reflects explosive strength capabilities (i.e. high power output) and generally results in better performance in sport [20]. Jump training can develop critical components of the stretch-shortening cycle (SSC); baseball competition often requires fast SSC utilization in a variety of positions and postures. Careful coordination of jump training, in combination with sprint training, will enhance the baseball athlete’s ability to overcome a static position, accelerate/decelerate, react to game-conditions, and transition out of a variety of athletic positions [13,20].

4) **Technological integration-** Technologies have proliferated the sports industry in the past decade. These tools offer instantaneous data collection and reporting capabilities previously unseen. This data can inform decision-making, challenge erroneous practices, mitigate injury risk, and potentially yield better competitive outcomes. As such, it is unsurprising various devices have been implemented en masse throughout baseball. The following section will provide examples of technological integration in baseball and provide some thoughts on their application.

    a. **Force Plate Analysis:** Force plate analysis has several applications in baseball. Previous studies have quantified ground reaction forces (GRF) in conjunction with pitching biomechanics to better understand optimal technique, methods of quantifying pitching load, and interactions between fatigue and stride length alterations [25-29]. In multiple studies, GRF profiles have been associated with arm velocity; both drive leg peak forces and landing leg breaking forces correlate with higher pitching velocities [25-26; 28]. Additionally, using a variety of dynamic and isometric tests, force plate analyses may be used for performance testing, fatigue monitoring and production of force-velocity profiles to inform the training process and/or exercise derivative selection [30-32].

b. **Motion Capture-** Motion Capture (MC) in baseball is commonly used to assess pitching biomechanics and quantify pitching load. Numerous studies have been conducted using MC to quantify joint kinetics/kinematics during pitching [1-2, 5, 8]. Additionally, many of these studies utilize MC in combination with force plate analysis and measurement of pitch velocity using a radar gun (or a proxy measurement of wrist velocity) [4, 25-26,28-29]. Findings from these studies have correlated specific biomechanical patterns (stride length, timing of maximal external rotation, ball release, etc.) with the magnitude and timing of GRF, higher ball velocities, and susceptibility to elbow injury [4, 25-26, 28-29]. Further, data from cadaveric literature and motion capture is incorporated into inverse or forward dynamic modeling to simulate applied forces throughout pitching. Such models can adjust specific variables and potentially elucidate individual contributions to the movement from various tissues or anatomical structures [33].

c. **Accelerometry/GPS-** Accelerometers and GPS units are capable of quantifying external load in training and competition. Some evidence suggests accelerometers may be a more accurate and precise tool to measure high-intensity actions (jumps, falls, etc.) and are therefore an apt choice for baseball [34]. Quantification of external workload allows the sport scientist or coach to monitor overall training load, more accurately prescribe a training stimulus, and assess the rate of progress. Additionally, accelerometry data may inform the coach of biomechanical inefficiencies in sprint capabilities that may be remediated by specific training emphasis.

d. **Inertial Measurement Unit (IMU)-** IMU have been used to collect data in a variety of dynamic tasks, such as gait analysis and countermovement jumps. IMU has recently been featured in baseball technology through the advent of the Motus Sleeve, providing real-time metrics throughout the pitching motion. Advocates of this product claim it is a valid and reliable wearable technology to assess modifiable factors such as arm slot, speed, and rotation [35]. However, these claims have not been received without controversy. In 2019, Driggers et al. (2019) [36] produced a letter to the editor challenging key claims of Camp et al. (2017) [35]. In summary, their key contentions were that:

    i. The methodological description of the validation study does not provide sufficient detail to appraise the validity of the device, nor replicate the study to confirm or deny its findings;
    ii. The data provided in the study seems incomplete;
    iii. The *r* values reports may be inflated due to the inclusion of pitchers from various competitive and demographic levels in one analysis;
    iv. The data reported is inconsistent with demographic data within the literature;
    v. The accuracy of the IMU data decreases as torques increase, which highly problematic considering applications in elite pitching;

vi. The accuracy data of the IMU reflects a heteroscedastic skew, contrary to the homoscedastic assumptions required for the statistical procedures employed;
vii. There is a lack of reliability data reported in the text.

These contentions certainly draw the use of this technology, in its current form, into question. These publications serve as a valuable case study for maintaining healthy skepticism when adopting and integrating technology.

5) **Limitations of Technology-** Sport Scientists should strive to maintain the integrity of their practice and be vigilant of the following factors when adopting new technologies:
   a. **Undeveloped or faulty technology-** Companies that commercialize technologies from academic or government research may not understand the underlying assumptions or limitations of the device.
   b. **Poor study design or analysis-** Validation studies produced in support of new technologies may not adopt the appropriate study design or statistical analysis to validate the device.
   c. **Lack of ecological validity-** Companies may seek to commercialize technologies that are not relevant to real-world, applied settings.
   d. **Conflict of Interest-** Companies may be reticent to acknowledge their conflicts of interest that would, rightly so, provoke hesitation from the consumer.
6) **Utilization of Data-** Sport Scientists should implement a clear vision for utilizing data. The following outlines potential objectives for the use of biomechanical data in baseball [20-24]:
   a. **Long-term athlete monitoring-** Examine longitudinal data to determine likely causes of plateau, biomechanical risk factors for injury, and optimal training methods.
   b. **Exploratory-** Determine topics which require further investigation related to baseball biomechanics; information which identifies a problem that is not well-defined provides a clear competitive advantage to the organization.
   c. **Retrospective-** Analyze previously collected data to test assumptions and/or findings within the literature related to biomechanics
   d. **Prognostic-** Assess biomechanical risk factors in a screening format
   e. **Monitoring Integration-** Use biomechanical data to inform training / recovery prescription (assignment of training load, rehabilitation timelines).

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