Level V Evidence

New Opportunities in Assessing Return to Performance in the Elite Athlete: Unifying Sports Medicine, Data Analytics, and Sports Science

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Abstract: Sports medicine literature has historically reported return to sport rates, but recent interest has shifted to return to previous performance. However, the measurement and understanding of performance in the elite athlete population has continued to evolve. Recent advancements in sport analytics, wearable technology, and player-tracking systems have improved our understanding of performance in the elite athlete. Sports medicine researchers should collaborate with sports science teams to continue investigating the validity and reliability of emerging technology, assist in interpretation of big data, and remain accountable to the goals of our athletic population. Future studies in sports medicine should consider using these detailed, granular assessments to address the demands of the elite athlete population.

Outcomes reporting continues to evolve as clinicians seek better methods of assessing the subjective and objective implications of injury and treatment.[1] The sports medicine literature has historically reported return to sport rates, but there is a ceiling effect to this measure, as patients may continue to subjectively improve even after returning to sport.[2-4] As a result, recent interest has shifted to return to previous performance to address the high expectations of the competitive athlete. However, defining and measuring meaningful performance has remained difficult for sports medicine clinicians and injury researchers. Although early studies used return to the same level of competition as a proxy of performance, recent studies have examined patient-reported subjective ratings and traditional player statistics to evaluate performance upon return from injury.[2,3,5,6] Although traditional statistics have long provided information on a player's

involvement in game events, these measures often are influenced by situational factors and sequencing, teammate abilities, and other game factors outside of a player's control. Because these statistics may not sufficiently represent individual performance, researchers have questioned their utilization and have recommended exploring new outcome measures to directly assess performance.[7,8]

In search for competitive advantages, many professional and collegiate sporting organizations have established sports science departments to develop and implement new methods of assessing and improving performance in their athletes.[9] This interest has produced both statistical and technological advancements leading to an exponential increase in data seeking to further evaluate sport performance.[10] Within these large datasets, there is ample opportunity for collaboration between sports scientists and sports medicine practitioners to decipher relevant measurable data and better align our professional goals with those of our athletes.

The purpose of this review is to describe how the understanding of sport performance has evolved with the development of data analytics, player tracking systems, and wearable technology, as well as to illustrate the opportunities for integration of these new measures in the sports medicine literature to address the demands of the elite athlete.

Data Analytics

In his book *Moneyball*, Michael Lewis chronicles the low-budget Oakland Athletics and their general

Table 1. John Smoltz's Season-Ending Statistics From 1996 to 2004

Year	Games Started	Wins	Innings Pitched	Strikeouts	Wins Above Replacement (WAR)
1996	35	24	253.3	276	8.4
1997	35	15	256	241	6.7
1998	26	17	167.2	173	5.2
1999	29	11	186.1	156	5.4
2001	5	3	59	57	1.3
2002	0	3	80.1	85	2.5
2003	0	0	64.1	73	2.9
2004	0	0	81.2	85	2.1

Table 2. Further Statistical Analysis of John Smoltz's 1996-2004 Seasons

Year	K/9	BB/9	HR/9	Fielding Independent Pitching (FIP)
1996	9.79	1.95	0.67	2.64
1997	8.47	2.21	0.74	3.04
1998	9.29	2.36	0.54	2.71
1999	7.53	1.93	0.68	3.14
2001	8.69	1.53	1.07	3.27
2002	9.52	2.69	0.45	2.39
2003	10.21	1.12	0.28	1.54
2004	9.37	1.43	0.88	2.72

BB, walks; HR, home run; K, strikeout.

manager, Billy Beane, while he sought new analytical measures to acquire undervalued players and gain competitive advantages against the wealthy, large-market organizations.[11] The book's publication and critical acclaim brought attention to the field of sabermetrics, defined by Bill James in 1980 as "the search for objective knowledge about baseball."[12] The subsequent proliferation of advanced analytics has changed the understanding of individual and team performance in the 21st century, and its utilization is commonplace at the professional level of many modern sports.[13-18] The National Football League (NFL) has seen increases in passing plays, 2-point conversion attempts, and fourth-down conversions while the National Basketball Association (NBA) has seen a drastic rise in 3-point attempts due to data-driven adjustments to team game strategy.[18,19]

In addition to optimizing team strategy, advanced analytics have been developed to better measure the individual performance of a player.[20] Basketball's Adjusted Plus-Minus statistic measures a player's impact on the team scoring margin while controlling for the strength of the opponent as well as the player's teammates.[21] In baseball, Fielding Independent Pitching (FIP), expected FIP, and Skill-Interactive ERA have been developed to quantify a pitcher's independent ability to prevent runs by using metrics that remove the role of the surrounding defense.[22] Given the improved ability to measure individual player performance, recent studies have begun to include advanced statistics while reporting surgical outcomes.[23-26]

John Smoltz, a Major League Baseball pitcher whose career lasted from 1988 to 2009, serves as an interesting case example in the assessment of postinjury performance. Before undergoing ulnar collateral ligament (UCL) reconstruction in 2000, he was a starting pitcher who had averaged 29.6 games started, 13.1 wins, 181.1 innings pitched (IP), and 174.8 strikeouts (K) per year. In the 4 seasons after returning from surgery, he averaged 1.25 games started, 1.5 wins, 71.1 IP, and 75 K per year. Table 1 illustrates his statistics for the 8 seasons occurring around his surgery in 2000.[22]

By cursory examination of Table 1, Smoltz had a statistical decline in the 4 seasons after surgery. The synthesis and subsequent analysis of these statistics for the sports medicine literature regarding return from UCL reconstruction would possibly report declines in "performance" of 57% to 96%. However, Smoltz had transitioned to the bullpen in 2001 to fill the team need at the closer position while also attempting to extend his career after early setbacks in his return from surgery.[27,28] In his new closer role, Smoltz would impact games in high-leverage situations, but he would be unable to match the workload of innings pitched from his time as a starting pitcher. By using analytics that control for the disparity in IP, a different conclusion on performance can be made (Table 2). Smoltz's average K/9 increased from 8.82 to 9.46, walks/9 decreased from 2.1 to 1.73, home runs/9 decreased from 0.67 to 0.66, and FIP decreased from 2.88 to 2.47. Therefore, he struck out batters at a higher rate while giving up a lower rate of walks and home runs. This improvement in performance is reflected by his decreased FIP, a metric that attempts to measure a pitcher's performance independent of factors outside of his control.[22] Although demonstrating a decline in many traditional statistics, John Smoltz was arguably one of the best relievers in professional baseball from the 2001 to 2004 seasons, and many statistics over this period compared favorably to Mariano Rivera, the New York Yankees closer considered by many to be the greatest closer of all-time.[22,29] John Smoltz returned to his former role as a starting pitcher in 2005, and he would subsequently become the first pitcher to be elected into the Hall of Fame after undergoing UCL reconstruction.[28]

However, understanding advanced analytics is critical to their interpretation. For example, Wins Above Replacement (WAR) quantifies the contribution of an individual's performance to the team relative to a replacement-level player.[22] In Table 1, Smoltz's WAR averaged 2.2 during the postoperative years of 2001-2004—a decrease from an average 6.4 WAR from 1996-1999. This decline in value starkly contrasts the

improvement in many other important pitching metrics. The formula for calculating WAR differs by position, and Smoltz's transition into the closer role affected how his WAR was calculated. As a closer, he produced high-quality work in high- leverage situations, but the quantity of overall work was low.[30] In addition, WAR is measured relative to a "replacement-level player." Due to the relative importance of preserving the final few innings to secure a win, the role of closer is often replaced by the next-best relief pitcher on the major league team in the case of an injury. Although a highly useful analytic, these calculation differences limit the ability for comparison of WAR between starting pitchers and relievers.

As professional sports become increasingly data-driven and their assessments of player performance continue to evolve, sports medicine researchers should further their understanding and utilization of advanced analytics to better assess individual performance in the elite athlete population.[11,31]

Motion Analysis and Wearable Technology

As far back as the 19th century, observers have attempted to discretely measure sport performance.[32] In 1822, Nicolas Mathieu Rieussec presented King Louis XVIII with a new invention—the stopwatch—to record and report the winning times of horseraces.[32] In 1878, photographer Eadweard Muybridge developed a 12-camera system to determine whether a sprinting horse was ever fully airborne. The groundbreaking series of photographs, *The Horse in Motion*, captured evidence of the aloft horse with all 4 hooves tucked underneath. This accomplishment unveiled the new possibility of assessing athletic motion through photography.[33]

In modern sport, technological advancements continue to allow for further analysis of athletic movement. Optoelectronic marker—based motion capture systems have largely been considered the gold standard for motion analysis, but the technology is expensive, difficult to interpret, and limited to controlled laboratory settings.[34,35] These systems also may be limited in their ability to provide accurate accelerations, forces, and torques during high-speed motions of many sports.[35] Due to these constraints as well as the desire to directly measure forces that were specific to certain athletic movements, wearable inertial measurement units were developed. The use of wearable technology has rapidly expanded, and this technology has been explored in recent health care and sports medicine research.[35-41] motusBASEBALL (Motus Global, Inc., Massapequa, NY) developed an arm sleeve for baseball players that houses an inertial measurement unit over the medial elbow to measure throw counts, peak elbow varus torque, arm speed, arm slot, maximum shoulder rotation, and workload, and

this technology has been used in numerous recent studies on training and rehabilitation programs.[42-45] A previous study has questioned the validity of reported magnitudes when compared with marker-based motion capture but found acceptable reliability.[46] Future studies should continue to assess the validity and reliability of similar devices, but there remains potential for using inertial measurement unit technology to assess the recovery of preinjury or surgery benchmarks in throwing athletes.

Professional sports organizations also have embraced wearable technology to monitor players under both game and practice environments.[47] Used by more than 2,000 sports teams, Catapult Sports (Catapult Innovations, Canberra Australia) developed a platform incorporating Global Positioning System technology, accelerometers, gyroscopes, and magnetometers that allow for workload monitoring as well as recording of maximal and average player velocities and acceleration.[48] Previous studies have assessed the validity and reliability of these systems.[49-51] Although recent literature has used Global Positioning System to study athlete workloads for injury prevention, there has been a paucity of literature on recovery from injury or surgery.[52-54] Future studies on the recovery of sprint speed or change of direction after anterior cruciate ligament reconstruction, for example, would be of interest to athletes whose sports require these skills.

The National Football League has recently partnered with Zebra Technologies to implement Next Gen Stats, a player and ball tracking system that uses radio-frequency identification chips that are embedded in every player and referee's uniform, game footballs, endzone pylons, and first-down markers.[55] The system captures speed, acceleration, distance traveled, and location within inches, and the resulting data have allowed for the generation of new performance measures and proprietary statistics.[55] NFL teams have adjusted draft grades and made decisions about free agency acquisitions based on on-field speed measurements that have differed from the traditional combine or pro day assessments of speed.[18] Although the NFL keeps the Next Gen Stats raw data private among the league and its organizations, statisticians and sports scientists have been able to use the limited publicly available data to measure passing game performance.[56]

Player-Tracking Systems

The recent development of optical player-tracking systems allows for real-time measurements of performance in competition environments. The NBA became the first American sports league to implement league-wide player tracking systems in 2013. Currently, an optical tracking system provided by Second Spectrum (Second Spectrum Inc, Los Angeles, CA) provides data on player speed, distance traveled, defensive impact,

shooting and scoring efficiency, and rebounding.[57] These data are readily available for fans and scientists to analyze, and recent sports medicine literature has used this data to assess player performance.[58] Similar to the NBA, Major League Baseball introduced StatCast in 2015, a spatiotemporal tracking system using a standardized optical camera system as well as radar technology to track player and ball movement.[59] This measurement system provides data on player positioning, sprinting speed, reaction time, hitting distance, launch angle, batted ball exit velocity, as well as various pitching metrics including velocity, pitch movement, and ball spin rate. Recent publications on pitching mechanics have begun to utilize this technology.[26,60]

The vast datasets that are available provide sports scientists and researchers with the possibilities of exploring new questions regarding injury and performance. For example, a recent study demonstrated that professional baseball hitters miss an average of 21 games after suffering an abdominal oblique injury.[61] Although this provides teams and players with valuable information regarding expected recovery timelines, little remains known about postinjury performance or risk factors for reinjury. StatCast data now allow researchers to investigate the relationship of injury to exit velocity, a critical marker of rotational performance that is dependent on the generated bat speed, pitch speed, and collision efficiency.[62] This information would serve important to professional baseball players, as 1-mph increases in exit velocity may correlate to 13% increases in home runs.[63] Yankees outfielder Aaron Judge was placed on the injured list on April 20, 2019, with an oblique injury. From the start of season until the time of injury, his average batted ball exit velocity was 98.4 mph. After returning from injury, his average exit velocity was 95.2 mph.[64] Whether an increased exit velocity raises the risk of subsequent oblique injury or exit velocity decreases after return from injury has yet to be studied. Regardless, access to these detailed performance data open new avenues in sports medicine research.

Conclusions

Advancements in sport analytics, wearable technology, and player-tracking systems have improved our understanding of performance in the elite athlete. Sports medicine researchers should collaborate with sports science teams to continue investigating the validity and reliability of emerging technology, assist in interpreting big data, and remain accountable to the goals of our athletic population. Future studies in sports medicine should consider using these detailed, granular assessments to address the demands of the elite athlete population.

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