



Original Research

Relationship between workload and throwing injury in varsity baseball players

Sameer Mehta

Medstar Georgetown University Hospital, Physical Medicine & Rehabilitation Department, 3800 Reservoir Road NW, Bles Bldg, Room CG12, Washington, DC, 20007, USA



ARTICLE INFO

Article history:

Received 25 April 2019
 Received in revised form
 1 August 2019
 Accepted 1 August 2019

Keywords:

Baseball
 Injury prevention
 Workload management
 Elbow torque
 Sports science
 Wearable technology

ABSTRACT

Objectives: In this study we describe the first analysis of the relationship between acute-to-chronic valgus workload ratio (ACVR) and injury in baseball.

Design: Observational study.

Setting: Competitive, team sport.

Participants: Eighteen, elite male baseball players (aged 17.0 ± 0.7 year, height 185 ± 5.7 cm, and mass 85.2 ± 7.6 kg) competing at the varsity level participated in this six-month study. Each player wore the motusTHROW™ sleeve and sensor during pre-season training and the entire 2017 regular season.

Main outcome measures: ACVR and injury.

Results: Overall there were a total of ten injuries recorded throughout the 2017 season amongst those wearing the sleeves, including six throwing-related injuries. Over 159 days of throwing, a total of 171,703 throws, and 1307 exposures were captured with the motusTHROW™ sensors. Five of the six throwing-related injuries occurred when athletes had an ACVR greater than 1.27, which marks the 75th percentile across all observations. Results from logistic regression suggested that ACVR was significantly related to injury occurrence ($p < .05$).

This resulted in an odds ratio of 15.2 and a risk ratio of 14.9, meaning that ACVR ratios above 1.27 were 14.9 times more likely to result in injury than ACVR ratios below 1.27.

Conclusions: Logistic regression reveals a significant relationship between ACVR and injury occurrence such that high ACVRs may increase injury risk.

© 2019 Elsevier Ltd. All rights reserved.

1. Background

Baseball continues to be one of the most popular sports from youth to professional level but also has reported a high prevalence of injuries with a rise in Tommy John surgeries, time lost to injury, and significant revenue losses (Conte, Camp, & Dines, 2016; Magra, Caine, & Maffuli, 2007; Posner, Cameron, Wolf, Belmont, & Owens, 2011). The average incidence of ulnar collateral ligament (UCL) reconstruction across all ages was 3.96 per 100,000 patients with the average incidence for 15–19-year-olds as high as 22.0 per 100,000 (Erickson et al., 2015). There are significantly more (56.8%) UCL procedures performed in 15–19-year-olds than any other age group and the incidence of UCL reconstruction is growing at a rate of 9.1% per year among this age group (Erickson et al., 2015). In addition, a recent epidemiology study of UCL reconstruction

amongst Major and Minor League Baseball pitchers from 1974 to 2016 found a steady increase in this procedure with 939 of 1429 reported cases occurring in Minor League Baseball pitchers with a median age of 22.4 years (Camp, Conte, D'Angelo, & Fealy, 2018). Thus, UCL reconstruction amongst the youth and younger age baseball athlete from high school to professional level continues to grow at a higher rate than any other age group.

Research has found a link between throwing volume and upper limb injuries in youth baseball that prompted USA Baseball to establish pitch limits for youth pitchers (Lyman et al., 2001). Establishing pitch counts and limits to throwing have shown to impact injury risk, however total throwing from all aspects of baseball has not been taken into consideration with pitch counts being the sole metric. Baseball ranked as the most participated team sport in the United States in 2016 where players find many opportunities to throw in the pre-season throwing program, in all different facets of practice depending on positional demands, in-season games, and further amplified with participation across

E-mail address: sameermehta@live.com.

various teams, tournaments, and showcases (Sports and Fitness Industry Association, 2016). Due to this extreme variability within the sport, it is difficult to only account for pitch limits and pitch counts as the sole objective measure to reduce risk of UCL injury. Therefore, it would be useful if all the throws and intensity of each throw, including those occurring outside of pitching could be monitored to gain an accurate reflection of the stress placed on the throwing arm during the sport.

Recent advances in wearable technology have facilitated the availability and subsequent utilization of these devices to individual athletes, sports teams, and to the general population to monitor functional movements, workloads, and biometric markers in an attempt to ultimately maximize performance and minimize injury. In addition, wearable sensors provide a method of monitoring training, practice, and actual competition (Fleisig, 2018; Li et al., 2016). With the advancement in technology and monitoring within sports comes the growth of analytics and data driven decision-making. Recent evidence has shown acute spikes in workload (as measured via the acute:chronic workload ratio, ACWR) can increase the risk of non-contact soft tissue injuries (Gabbett, 2016). This ratio of average workload over 1 week as compared to average workload over four weeks is the ACWR. These findings have been validated in multiple sports, Australian football, cricket and rugby league (Gabbett, 2016), demonstrating that injury likelihood is low (<10%) when the acute:chronic load ratio is within the range of 0.8–1.3. However, when the acute:chronic load ratio exceeds 1.5 (ie, the load in the most recent week is 1.5 times greater than the average of the last 4 weeks), the likelihood of injury more than doubles.

Despite the alarming rise in injury rate and ulnar collateral ligament (UCL) reconstruction there is no published evidence investigating the relationship between workload in the throwing arm, specifically the valgus stress on the UCL, and upper limb injury in baseball players. Therefore, in this study we describe the first analysis of the relationship between acute-to-chronic valgus workload ratio (ACVR) and injury in baseball.

2. Methods

Eighteen male baseball players (aged 17.0 ± 0.7 year, height 185 ± 5.7 cm, and mass 85.2 ± 7.6 kg) competing at the varsity high school level participated in this six-month observational study. Players were selected at random by the head coach with inclusion criteria: a single sport varsity, baseball athlete solely playing at this institution. Each player wore the motusTHROW™ sleeve and sensor during pre-season training and the entire 2017 regular season as a part of the baseball program. This study was exempt from Institutional Review Board (IRB) approval because it did not meet human subjects criteria and all data set forth for analysis was de-identified. All athletes were uninjured upon initiation of data capture and were cleared by a physician for their preseason physicals despite potentially having a past medical history of upper extremity injury (Table 1). The motusTHROW™ sensor (Fig. 1) is a valid and reliable inertial measurement unit deemed excellent by internal and third party peer-reviewed studies (Boddy et al., 2019; Camp et al., 2017; Makhni et al., 2018; Melugin et al., 2019). The sensor monitors throwing variables such as: arm slot (degrees, °), arm speed (degrees per second, °/s), maximum shoulder external rotation (degrees, °), and peak elbow valgus torque (Newton-meters, Nm).

In 2016, this sensor was approved by Major League Baseball as the official wearable technology for in-game use. In addition, over 82,000 throws amongst professional baseball pitchers was recently shown to provide a valid measure of throwing arm mechanics and elbow varus torque (Camp et al., 2017). The sensor weighs approximately 7 g and when it is worn for an extended period of time, allows for calculation of cumulative workload on the

Table 1
Injury details.

| Injury Location | Diagnoses | Mechanism | Position | PMHx | ACVR |
|-----------------|-----------------------------|--------------|-----------------|--------------------------|------|
| Elbow | Medial epicondylitis | Throwing | Pitcher | N | 1.39 |
| Elbow | UCL | Pitching | 3B/Pitcher | N | 1.1 |
| Shoulder | SLAP (non-dominant SH) | Throwing | 1B/Pitcher | R UCL sprain 3 yrs prior | 1.34 |
| Shoulder | Biceps Tendinitis* | Fall on SH | 1B/Pitcher | HS | 1.0 |
| Shoulder | Biceps Tendinitis | Throwing | Pitcher | SH pain | 1.4 |
| Shoulder | Rotator Cuff Tendinitis | Throwing | Utility/Pitcher | N | 1.51 |
| Shoulder | Rotator Cuff Tendinitis* | Throwing | 1B/Pitcher | HS | 1.33 |
| Neck | Cervical Strain | Pitching | Pitcher | SH pain | 1.4 |
| Knee | Patella tendonitis | Base-running | 2B/Pitcher | N | 1.53 |
| Ankle | Gastrocnemius/Soleus strain | Pitching | 1B/Pitcher | N | .63 |

Shaded: throwing-related injury

Unshaded: non-throwing related injury

*Indicates two injuries on same player although symptoms had completely resolved and experienced new injury 6 weeks after recovering from new injury.

N: none

HS: hamstring strain

SH: shoulder



Fig. 1. MotusTHROW™ Sleeve and Sensor.

throwing arm. Each day data from all the sensors were transferred to a mobile or tablet device by the team data manager and wirelessly backed up on a secure, server for data redundancy.

Of the eighteen athletes, fourteen (78%) pitched at least one inning in one game and were classified in this study as pitchers, 2 (11%) were catchers, and 2 (11%) were fielders.

Sleeves were worn consistently on a daily basis during practice, game, and during any throwing attempt throughout the duration of the six months. All injuries were tracked and logged via an application called Player's Health (Player's Health, Minneapolis, MN) to ensure consistency of injury recording throughout the course of the season. This uniform platform provides athletic organizations with medical information and injury reporting via a HIPAA (Health Insurance Portability and Accountability Act) compliant mobile application. Player's Health allowed for accurate reporting by enabling collaboration and communication between all those involved in athlete well-being including the parents, sports medicine and coaching staff. All injury reporting was completed by the

sports medicine staff. Injury was defined as those seeking medical attention from a health care professional due to pain or inability to participate in sport. Over 159 days of throwing, a total of 171,703 throws and total of 1307 athletic exposures were captured with the motusTHROW™ sensors. All captured data were deidentified when statistical analysis was performed.

The ACVR was calculated where the acute workload was a 7-day rolling average of daily workload and the chronic was a 28-day rolling average of daily workload. The 7-day period was coupled within the 28-day timeframe. Daily workloads are computed as the sum of workload for each throw, which was truly measuring the sum of the valgus stresses incurred from each throw that day. In addition, when injury occurred after a higher ACVR ratio followed by cessation of throwing, this non-throwing was included to calculate the acute and chronic workloads.

Logistic regression was utilized to estimate the effect of ACVR on injury occurrence. Statistical analyses were conducted in R version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Overall there were a total of ten injuries recorded throughout the 2017 season amongst those wearing the sleeves with six throwing-related injuries on the dominant arm (Table 1). Injuries were diagnosed by a member of the sports medicine staff, consulting orthopedic physician, and/or appropriate diagnostic imaging. Five of the six throwing-related injuries occurred when athletes had an ACVR greater than 1.27, which marked the 75th percentile across all observations. Furthermore, results of logistic regression suggested that ACVR was significantly related to injury occurrence ($p < .05$). This proposed that athletes may be at higher risk of injury at higher ACVRs.

This model resulted in a workload ratio coefficient (or log odds) of 2.756 (95% CI 0.05–5.1), which equates to odds of 15.7. This suggests that for every 0.1 increase in workload ratio, the odds of injury increase by a factor of 1.3. Also, it showed an odds ratio of 15.2 and a risk ratio of 14.9. Thus, when comparing injury occurrences about the 75th percentile of ACVR, ratios above 1.27 had a risk ratio of 14.9, meaning ratios above 1.27 were 14.9 times more likely to result in an injury.

There were four non-throwing related injuries to the upper and lower extremity we could not generate statistical correlation to ACVR since the wearable sensor technology was worn on the throwing arm and captured data from this limb only. Mean ACVR amongst injured and healthy players was 1.35 (SD \pm 0.14) and 1.12 (SD \pm 0.26), respectively. The mean ACVR was the average workload ratio for those injured at time of injury and those healthy. These data were pooled to control for athletes having varying amounts of throws.

4. Discussion

Results from the logistic regression indicate there is a significant relationship between ACVR and throwing injury occurrence ($p < .05$), where higher ACVR ratios are associated with increased injury risk. Five of the six throwing related injuries occurred when athletes had an ACVR greater than 1.27, and those who fell in this zone of increased risk were 14.9 times more likely to result in injury than when workload ratios were below 1.27. This principal finding is in agreement with other studies that have shown that rapid spikes in workload increased injury risk in Australian rules football, rugby league, and cricket players (Gabbett, 2016). These findings suggest that monitoring the ACVR may provide a method of reducing injury risk in the baseball athlete.

Previous research has taken into consideration throwing arm

stress, with pitch count per game and pitch count per season associated with shoulder and elbow injury in youth baseball (Lyman, Fleisig, Andrews, & Osinski, 2002; Lyman et al., 2001; Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). An observational study of high school pitchers on game days indicated 42% of throws were unaccounted for during preparation for pitching bouts. (Zaremski et al., 2018). Although this can be considered a workload variable it did not take into consideration cumulative throwing volume and intensity on day of throwing and all previous days leading up to and after date of competition. Moreover, a key limitation of these previous baseball studies is a lack of intensity measurement on pitches, where maximal and submaximal effort throws have demonstrated variability in kinetics and kinematics (Lyman et al., 2002; Okoroha et al., 2018b; Slowik et al., 2019; Whiteley, 2007).

This is the first study to investigate the relationship between ACVR and upper limb injury, capturing throws in preseason, during the season, and in game resulting in cumulative throwing volume, effort, and workload. Throws captured included every instant an athlete threw a baseball, from playing catch ten feet away to throwing at one hundred percent from the pitching mound to a live batter in game. In addition, all these data were recorded via a valid, inertial measurement unit (motusThrow™) (Boddy et al., 2019; Camp et al., 2017; Makhni et al., 2018). This study has shown a significant association between higher throwing workload ACVR and upper limb injury risk in varsity, high school baseball players.

4.1. Key findings

A key finding from this study was mean ACVR amongst injured players were higher than the healthy players. This further supports the impact of total throwing volume and intensity on risk of throwing injury over a duration of time. Players that have dual position responsibilities such as infielders and pitchers have a greater impact on ACVR with volume and effort, whereas a catcher only tips the scale towards having more volume and less towards effort. These true analytical findings have a crucial impact not only on ACVR but also as actionable data that coaches, sports scientists, performance and sports medicine professionals can utilize to modify workload. This can reduce injury risk, enhance performance, and serve as an objective marker to ensure safe integration when making return to play decisions. Sports specific tasks like longtoss, stations, flatgrounds, bullpen sessions, team defensive drills during practice, live games, and even playing catch render different volumes, efforts, and stress patterns per baseball athlete and per position (Okoroha et al., 2018a, 2018b; Slowik et al., 2019). Establishing metrics for these tasks allow the appropriate staff to devise strategies to modify workload accordingly and facilitates data-driven decision-making. It is important to consider anatomic changes found on magnetic resonance imaging (MRI) of an overhead throwing athlete do not always correlate with the athlete's symptom complaints where soft tissue or osseous changes are considered normal adaptations to stress on a pitcher's throwing arm (Hurd, Eby, Kaufman, & Murthy, 2011). Thus, we can look towards workload management as a way to find solutions to these potential dormant asymptomatic issues that are related to the demands of the sport instead of trying to find an intervention for a normal finding found on imaging.

Limitations of this study include not being able to track workload over a whole year of participation in the sport, athletes with more than one injury, smaller sample size, and potential players not commenting on pain in fear of losing playing time. A limitation of this study was not being able to capture workload data during summer and fall baseball where athletes may participate with another team and serve a different role from their primary team

with respect to volume, effort, and overall ACVR. Likewise, this investigation was focused on workload ratio and injury not total workload which warrants a further study in the future. Many baseball players in the United States are throwing all year round and rarely take much respite from this task with a growing trend towards early sport specialization (Wilhelm, Choi, & Deitch, 2017). Similarly, with the participation and specialization we have seen the upper extremity as the most common location of injuries in high school baseball (Rechel, Yard, & Comstock, 2008). In addition, another limitation of this study are those athletes with more than one injury during the duration of data capture. One athlete had a contact non-throwing related injury on the throwing arm early in the season and then later in the season also experienced a throwing related injury on the same limb. Although the athlete healed from the previous injury it is worth considering that it was on the same limb. This along with past medical history of upper extremity injury need to be considered as confounding variables for increased risk of future injury (Bittencourt et al., 2016). Statistically, the 95% confidence interval implies a strong effect size but more subjects would have to be involved in the study to narrow the confidence interval.

4.2. Future research

Future studies in this area should involve tracking ACVR throughout the year to account for stress on the arm across the full throwing duration and offseason. This will allow a closer examination of a player's chronic workload during year round play. Similarly, gathering workload data across different age groups and levels of baseball can vary amongst teams, at different levels of the sport, along with the positional demands changing with age. Also, the number of games and the number of players who must pitch more due to talent of their team can drastically vary. Ultimately, capturing volume and intensity, the basic measure of workload, over the course of a season can potentially impact the ACVR or workload ratio values.

4.3. Practical applications

This study demonstrated that an increased throwing workload and higher ACVR were associated with an increased risk of upper limb injury in varsity baseball players. Avoiding spikes in throwing workload over the course of a week by ensuring appropriate chronic loading patterns over a longer period (e.g. month) may build a more robust athlete. Coaching staff and personnel involved with baseball can use this information to avoid excessive throwing stress and attempt to avoid acute spikes in workload as it places the athlete at a greater risk of injury. Similarly, building chronic stress patterns by prescribing appropriate amount and intensity of throwing over time can also serve to reduce injury risk. The simple action of adopting utilization of wearable technology can give profound, reliable insight into the workload placed on the upper extremity with simple metrics like volume and intensity. Moreover, the principal finding from this study can act as a valid methodology to assist all those involved in the health and performance of baseball athletes, including: the athlete, parents, coaches, sports scientists, performance staff, and sports medicine clinicians.

5. Conclusion

Logistic regression reveals a significant relationship between ACVR and throwing-related injury occurrence such that high ACVRs may increase injury risk. Players should avoid sudden spikes in acute workload to minimize the risk of injury to the throwing arm. Load management can be achieved by modifying volume of throws, high effort throws, and variables impacting workload, arm slot ($^{\circ}$),

arm speed ($^{\circ}/s$), maximum shoulder external rotation ($^{\circ}$), and peak elbow valgus torque (Nm).

This data-driven methodology of managing ACVR can serve as a valid tool to assist clinicians, coaches, and athletes with reducing injury risk and modifying workload to optimize athlete health and performance.

What is known about the subject

18 male, varsity high school baseball players competing in an elite, nationally ranked baseball program.

What this study adds

This data-driven methodology of managing ACVR can serve as a groundbreaking tool to assist clinicians, coaches, and athletes with reducing injury risk and modifying workload accordingly to keep the athlete healthy.

Contributorship statement

The author has made a substantial contribution to the design, drafting, and the revising of the manuscript and has also read and approved the final version. The author has no direct or indirect financial incentive associated with publishing this article.

Conflicts of interest

None declared.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Sharing

Data not available.

Ethical approval

Please see attached approval by institutional review board.

Patient involvement

This study did not involve patients.

Acknowledgements

Special thanks to Medstar Georgetown University Hospital, St. John's College High School Baseball and Sports Medicine staff, Motus Global, Players Health, Travis Tubbs, and John Varney.

This research paper was presented at the 2nd World Congress of Sports Physical Therapy at the Optimal Loading in Sport in Belfast, Ireland and received the oral, paper research award.

References

- Bittencourt, N. F. N., Meeuwisse, W. H., Mendonça, L. D., Nettel-Aguirre, A., Ocarino, J. M., & Fonseca, S. T. (2016). Complex systems approach for sports injuries: Moving from risk factor identification to injury pattern recognition – narrative review and new concept. *British Journal of Sports Medicine*, 50, 1309–1314.
- Boddy, K. J., Marsh, J. A., Caravan, A., Lindley, K. E., Scheffey, J. O., & O'Connell, M. E. (2019). Exploring wearable sensors as an alternative to marker based motion capture in the pitching delivery. *PeerJ*, 1–15.
- Camp, C. L., Conte, S., D'Angelo, J., & Fealy, S. A. (2018). Epidemiology of ulnar

- collateral ligament reconstruction in major and minor league baseball pitchers: Comprehensive report of 1429 cases. *Journal of Shoulder and Elbow Surgery*, 27, 871–878.
- Camp, C. L., Tubbs, T. G., Fleisig, G. S., Dines, J. S., Dines, D. M., Altchek, D. W., & Dowling, B. (2017). The relationship of throwing arm mechanics and elbow varus torque: With-in subject variation for professional baseball pitchers across 82,000 throws. *The American Journal of Sports Medicine*, 45(13), 3030–3035.
- Conte, S., Camp, C. L., & Dines, J. S. (2016 Mar-Apr). Injury trends in major league baseball over 18 seasons: 1998–2015. *American Journal of Orthopedics*, 45(3), 116–123.
- Erickson, B. J., Nwachukwu, B. U., Rosas, S., Schairer, W. W., McCormick, F. M., Bach, B. R., Jr, Bush-Joseph, C. A., & Romeo, A. A. (2015). Trends in medial ulnar collateral ligament reconstruction in the United States. *The American Journal of Sports Medicine*, 43(7), 1770–1774.
- Fleisig, G. S. (2018). Editorial commentary: Changing times in sports biomechanics: Baseball pitching injuries and emerging wearable technology. *Arthroscopy*, 34(3), 823–824.
- Gabbett, T. (2016). The training-injury prevention paradox. Should athletes be training smarter and harder? *British Journal of Sports Medicine*, 0, 1–9.
- Hurd, W. J., Eby, S., Kaufman, K. R., & Murthy, N. S. (2011). Magnetic resonance imaging of the throwing elbow in the uninjured, high school-aged baseball pitcher. *The American Journal of Sports Medicine*, 39(4), 722–728.
- Li, R. T., Kling, S. R., Salata, M. J., Cupp, S. A., Sheehan, J., & Voos, J. E. (2016). Wearable performance devices in sports medicine. *Sport Health*, 8(1), 74–78.
- Lyman, S., Fleisig, G. S., Andrews, J. R., & Osinski, E. D. (2002). Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *The American Journal of Sports Medicine*, 30, 463–8.
- Lyman, S., Fleisig, G. S., Waterbor, J. W., Funkhouser, E. M., Pulley, L., Andrews, J. R., Osinski, E. D., & Roseman, J. M. (2001 Nov). Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine & Science in Sports & Exercise*, 33(11), 1803–1810.
- Magra, M., Caine, D., & Maffuli, N. (2007). A review of epidemiology of pediatric elbow injuries in sports. *Sports Medicine*, 37(8), 717–735.
- Makhni, E. C., Lizzio, V. A., Meta, F., Stephens, J. P., Okoroa, K. R., & Moutzouros, V. (2018). Assessment of elbow torque and other parameters during the pitching motion: Comparison of fastball, curveball, and changeup. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 34(3), 816–822.
- Melugin, H., Larson, D. R., Fleisig, G. S., Conte, S., Fealy, S. A., Dines, J. S., D'Angelo, J., & Camp, C. L. (2019). Baseball pitchers' perceived effort does not match actual measured effort during a structured long-toss throwing program. *The American Journal of Sports Medicine*, 47(8), 1949–1954.
- Okoroa, K. R., Lizzio, V. A., Meta, F., Ahmad, C. S., Moutzouros, V., & Makhni, E. C. (2018). Predictors of elbow torque among youth and adolescent baseball pitchers. *The American Journal of Sports Medicine*, 46(9), 2148–2153.
- Okoroa, K. R., Meldau, J. E., Lizzio, V. A., Meta, F., Stephens, J. P., Moutzouros, V., & Makhni, E. C. (2018). Effect of fatigue on medial elbow torque in baseball pitchers: A simulated game analysis. *The American Journal of Sports Medicine*, 46(10), 2509–2513.
- Olsen, S. J., 2nd, Fleisig, G. S., Dun, S., Loftice, J., & Andrews, J. R. (2006). Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *The American Journal of Sports Medicine*, 34, 905–912.
- Posner, M., Cameron, K. L., Wolf, J. M., Belmont, P. J., Jr, & Owens, B. D. (2011 Aug). Epidemiology of major league baseball injuries. *The American Journal of Sports Medicine*, 39(8), 1676–1680.
- Rechel, J. A., Yard, E. E., & Comstock, R. D. (2008). An epidemiologic comparison of high school sports injuries sustained in practice and competition. *Journal of Athletic Training*, 43(2), 197–204.
- Slowik, J. S., Aune, K. T., Diffendaffer, A. Z., Cain, E. L., Dugas, J. R., & Fleisig, G. (2019). Fastball velocity and elbow-varus torque in professional baseball pitchers. *Journal of Athletic Training*, 54(3), 296–301.
- Sports and Fitness Industry Association. (2016). *Baseball participation report*. https://www.sfia.org/reports/416_Baseball-Participation-Report-2016. (Accessed 2 March 2018). Published June 4, 2016.
- Whiteley, R. (2007). Baseball throwing mechanics as they related to pathology and performance - a review. *Journal of Sports Science and Medicine*, 6, 1–20.
- Wilhelm, A., Choi, C., & Deitch, J. (2017). Early sport specialization: Effectiveness and risk of injury in professional baseball players. *Orthopaedic Journal of Sports Medicine*, 5(9), 1–5.
- Zaremski, J. L., Zeppieri, G., Jr, Jones, D. L., Tripp, B. L., Bruner, M., Vincent, H. K., & Horodyski, M. (2018). Unaccounted workload factor: Game-day pitch counts in high school baseball pitchers—an observational study. *Orthopaedic Journal of Sports Medicine*, 6(4), 1–7.