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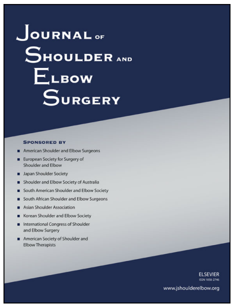

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Garrett S. Bullock, PT, DPT, DPhil, Charles A. Thigpen, ATC, PT, PhD, Hannah Zhao, SPT, Laurie Devaney, PT, ATC, PhD, Daniel Kline, PT, DPT, SCS, ATC, Thomas J. Noonan, MD, Michael J. Kissenberth, MD, Ellen Shanley, PT, PhD, OCS

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Short Title: Prognostic Value of Neck Motion in Baseball

Authors: Garrett S. Bullock, PT, DPT, DPhil,*[1,2] Charles A. Thigpen ATC, PT, PhD,*[3] Hannah Zhao, SPT,[4] Laurie Devaney, PT, ATC, PhD,[5] Daniel Kline, PT, DPT, SCS, ATC,[3] Thomas J. Noonan, MD,[6,7] Michael J. Kissenberth, MD,[8] Ellen Shanley, PT, PhD, OCS,[4]

1. Department of Orthopaedic Surgery, Wake Forest University School of Medicine, Winston-Salem, NC, USA
2. Department of Biostatistics and Data Science, Wake Forest University School of Medicine, Winston-Salem, NC, USA
3. ATI Physical Therapy, Greenville, SC, USA
4. Doctor of Physical Therapy Program, Duke University School of Medicine, Durham, NC, USA
5. Department of Kinesiology, College of Agriculture, Health, and Natural Resources, University of Connecticut, Storrs, CT, USA
6. Department of Orthopaedic Surgery, University of Colorado School of Medicine, Boulder, CO, USA
7. University of Colorado Health, Steadman Hawkins Clinic, Englewood, CO, USA
8. Steadman Hawkins Clinic of the Carolinas, Greenville, SC, USA

***These author share joint first authorship.**

Corresponding Author: Garrett S. Bullock, PT, DPT, DPhil, Wake Forest School of Medicine, 475 Vine St., Winston-Salem, NC 27701, USA; garrettbullock@gmail.com

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Abstract

Background: Authors have observed an association between cervical spine mobility and arm injury risk in baseball player; however, there is a need to assess the generalizability of cervical measurement data. Assessing the downstream of associations of cervical dysfunction on shoulder and elbow injuries can inform clinical interventions to help reduce future arm injuries. The purpose of this study was to assess the generalizability of neck range of motion measures as arm injury prognostic factors in professional baseball pitchers.

Methods: A prospective cohort of professional baseball pitchers in one Major League Baseball Organization was performed. Pitchers underwent pre-season neck range of motion including cervical flexion, extension, rotation, lateral flexion, and the flexion-rotation test (CFRT) and were followed for the season. The outcome was the occurrence of shoulder or elbow injury. A Cox proportional hazards analysis was performed and reported as hazard ratios (HR) with 95% confidence intervals (95% CI).

Results: A total of 88 pitchers were included (Age: 24.2 (2.4); Left-Handed: 21 (23%); Fastball Velocity: 92.3 (1.8)), with 15,942 athlete exposure days collected over the season. Pitcher neck range of motion was assessed (Flexion: 64 (10); Extension: 69 (11); Difference in Lateral Flexion: -1 (7); Difference in Neck Rotation: -2 (9); Difference in CFRT: -1 (7)). A total of 20 arm injuries (Shoulder: 9 (10%); Elbow: 11 (13%); Combined Rate: 1.3 (95% CI: 0.7, 1.7) per 1000 exposure days) were suffered by pitchers during the season. For every degree increase in the difference in dominant (rotating to dominant shoulder) versus non-dominant (rotating to non-dominant shoulder) neck rotation, there was a four-fold increase in arm injury hazard (HR: 4.0 (95% CI: 1.1, 13.9), $p = 0.031$). No other neck measurements demonstrated prognostic value.

Conclusions: A deficit in dominant versus non-dominant neck rotation was prognostic for pitching arm injury. However, the cervical rotation test did not have prognostic value in this sample. Further research is required to assess the generalizability and scalability of neck range of

motion assessment in relation to baseball shoulder and elbow injuries across different competition levels.

Keywords: Cervical; Injury Risk; Clinical Factors; Shoulder; Elbow; Injury Prevention

Level of Evidence: Level I; Prospective Cohort Design; Prognosis Study

Despite efforts to identify prognostic factors and modify injury prevention strategies, baseball shoulder and elbow injuries are complex in nature and have continued to rise across all age groups over the past decade.[12,20,38,40] Specifically, injuries to the elbow and shoulder in professional baseball pitchers are highly prevalent, with up to 25% of players undergoing an ulnar collateral ligament reconstruction.[15,20] Extrinsic risk factors including pitch count,[6] pitch velocity,[29] and throwing mechanics,[8] as well as intrinsic risk factors including shoulder range of motion[40] and humeral torsion[30] have been shown to impact injuries. Arm injury incidence remains high, likely due to the dynamic, interconnected network of intrinsic and extrinsic factors that are required to pitch at a professional level.[41]

Pitchers transfer load throughout the kinetic chain to generate force while dampening stress on the shoulder and elbow to achieve optimal pitch velocity.[19] With the intricate interplay between the spine and upper extremity during the pitching motion, restrictions in neck mobility may lead to compensations throughout the kinetic chain and have a carryover effect to the shoulder or elbow (Figure 1).[49] In a previous study,[43] cervical spine position and poor posture prevented optimal scapular kinematics and muscle activation, specifically in shoulder flexion and overhead reaching activities.[49] Similar to how deficits in glenohumeral passive range of motion increase the risk for elbow injuries,[45,46] neck range of motion may impact shoulder and elbow injury risk.[16] These findings are consistent with a recent cohort study of 49 healthy, collegiate baseball pitchers that reported an association between preseason neck mobility and risk of in-season shoulder and elbow disability and self-reported pain and disability.[16] Specifically, limited range of motion in the cervical rotation flexion test on the dominant side and neck flexion range of motion were associated with over 9 times increased risk of injury.[16]

Authors have determined a relationship between neck mobility and arm injury risk in small select sample[16,48]; however, it is imperative to evaluate the generalizability of neck clinical assessments as arm injury risk prognostic factors to decipher their utility across different throwing athlete populations. Therefore, the purpose of this study was to assess the generalizability of neck range of motion measures as arm injury prognostic factors in professional baseball pitchers. It is hypothesized neck range of motion will demonstrate arm injury prognostic factors. These data will provide clinical tools for improving arm injury risk assessments in professional baseball pitchers.

Materials and Methods

Study Design

A prospective cohort study was conducted from February to September during the 2023 season on Minor League Baseball (MiLB) pitchers in one Major League Baseball (MLB) organization. The Strengthening the Reporting of Observational Studies in Epidemiology for Sport Injury and Illness Surveillance (STROBE-SIIS) was used to inform study reporting.[21] Prior to data collection, all participants were informed of the risks and benefits of participating in the study, then provided verbal and written consent. Pitchers then underwent routine physical examination and injury screening during preseason medical physicals at the spring training complex prior to participating in baseball related activities. All examiners were blinded to hand dominance.[38] Throughout Spring training and the MiLB season, pitchers were monitored for athletic exposures and injuries at their respective affiliate teams. This study was approved by the Health System Institutional Review Board.

Patient and Public Involvement

This study comes directly through official and unofficial discussions of the needs of the MLB organization concerning risk factor assessment and reducing the injury burden within the organization. An official meeting following the MLB season was performed with organization sports medicine and performance knowledge users on potential scientific investigations needed by the organization. Further follow-up phone call and virtual meetings were performed to identify the exact scientific investigation. The MLB organization sports medicine team assisted in collecting the data. Presentations and workshops were performed to disseminate the findings and to educate knowledge users on assessments and interventions to intervene on these scientific findings.

Study Participants

Minor League Baseball pitchers, from one MLB organization, were included in this study. Inclusion criteria consisted of 1) Currently participating in all baseball related training, practices, and competitions. Exclusion criteria consisted of 1) Currently injured or not participating in all training, practices, or spring training competitions; 2) Participating at MLB spring training; 3) Signed a professional contract in the middle of the season; 4) Sustained a traumatic injury, which involved collision with another athlete, the ground, or inanimate object during the season.

Raters

One rater with over 20 years of sports medicine experience collected all neck range of motion data. Two raters with each over 20 years of sports medicine experience collected all shoulder data throughout the prospective cohort time period. Raters for shoulder data collection achieved excellent inter-reliability prior to data collection.

Clinical Assessment

Neck Range of Motion

Neck active range of motion was measured for flexion, extension, lateral flexion, and rotation with a digital inclinometer device (Easy Angle; MeloqAB Incorporated, Stockholm, Sweden) as previously described.[2,16] The digital inclinometer has demonstrated excellent inter- and intra-rater reliability and reproducibility (ICC: 0.93-0.98; SEM: 1.6-2.8; MDC: 3.6-6.5) across the six neck movements.[2] Lateral flexion and rotation were measured for both sides. The rater demonstrated the neck motions and participants performed a practice trial for each motion prior to measurement. All active neck movements were performed twice, and the mean of the two trials was recorded.[16] Dominant rotation was defined as rotation to the dominant shoulder. Non-dominant rotation was defined as rotation to the non-dominant shoulder.

Following measurement of active neck range of motion, the same rater performed the Cervical Flexion-Rotation Test (CFRT) as described previously.[15] The CFRT consisted of flexing the neck and resting occiput on the examiner's abdomen. The goniometer was positioned at the middle of the top of the head. The head was passively rotated until firm resistance.[15] The CFRT is a valid and reliable test purported to identify impaired upper cervical mobility.[3] There were 2 trials performed in each direction, and the mean of the 2 trials was recorded.[16]

Shoulder Range of Motion

Shoulder ROM (external (ER), internal (IR) rotation and horizontal adduction (HA)) were measured in the supine position for both arms using a digital inclinometer per previously described methods.[17,18,25,31,37,38,40,44] Briefly, for shoulder ER and IR, shoulders were positioned in 90 degrees of shoulder abduction and elbow flexion. A small towel roll was placed under the humerus to maintain humeral position. Shoulder ER and IR were performed passively, with gravity acting upon the arm. A digital inclinometer was placed on the forearm midline and aligned to the olecranon process.[5] For HA, the scapula was retracted and stabilized via the thenar eminence of one examiner placing an anterior to posterior pressure to the lateral scapular border. The upper extremity was then placed in 90 degrees abduction in zero degrees rotation and passively horizontally adducted across the body.[23,26,39] A digital inclinometer, placed on the posterior border of the humerus, in line with the olecranon and acromial processes, measured the angle between the humerus and the horizontal plane, from the superior aspect of the shoulder. Shoulder ER and IR were summed to measure total ROM (TROM). The difference between dominant (D) and non-dominant (ND) shoulder ROM (S-S) were also calculated for ER, IR, HA, and TROM.[45,47] Two trials were performed for each test, with the mean of the 2 trials recorded. Prior to data collection, all measures were assessed for reliability and demonstrated acceptable inter- and intra-rater reliability (ICC $_{(2,1)}$ =0.92 - 0.99).[37]

Exposures and Outcomes

Athlete Exposure definition

An athlete-exposure (AE) was defined as one athlete participating in one practice or competition where a player was at risk of sustaining an injury.[34] Baseball exposure was defined from the beginning of preseason (i.e. spring training) to the end of the MiLB season.[32] Spring training is defined as organized practice and competitions by the MLB parent organization prior to the MLB or MiLB season. MLB and MiLB spring trainings are separate but held at the same baseball site. Spring training occurs between February and early April. Pitching appearance exposure was defined as a pitcher throwing at least one pitch within a game.[41] Innings pitched exposure was defined as obtaining at least one out (i.e., 1/3 of an inning) within a game.[41]

Injury Definition

An injury was defined as an injury to a tendon, ligament, nerve, muscle, or bone that occurs during any baseball team sponsored activity or event[36] was followed by at least one day of missed practice or game and received medical attention from a medical professional.[38] If a player was unavailable to play for injury prevention reasons (i.e., has reached league or individually determined pitch or innings count limits), then their absence was not considered as an injury.[32] Injuries were defined by the Orchard Sports Injury Classification system and arm injuries stratified by shoulder/clavicle, upper arm, elbow, and forearm.[35] All injuries and illness were recorded, and time loss was taken into account for overall exposure.[33] Injury severity was further classified by time loss of one to six days (TL1-6) from participation in practice of games, time loss of 7-27 days (TL7-27), and time loss of 28+ days (TL28).[33]

Outcomes

The outcome was sustaining an arm (shoulder or elbow injury) during the season.[10]

Covariates

Covariates were determined through clinical reasoning amongst the study team and a detailed review of the relevant literature. Covariates controlled for included: pitching role (i.e., starter versus reliever),[10] number of pitching appearances,[14,22] innings pitched,[6] fastball pitching velocity,[27-29] and shoulder internal rotation difference.[7]

Statistical Analyses

Prior to data analyses, missing data were assessed for missing data prevalence, patterns of missingness, and mechanisms of missingness (Appendix 1). Missing data were low (<1%), with no discernable missing data pattern, a complete case analysis was performed.

Measurements

Neck and shoulder measurements were reported as mean (SD), and demographic variables were reported as frequency (percent) or mean (SD).

Epidemiological Calculations

All epidemiological calculations were calculated for the entire cohort. Overall injury rates (i.e., all injuries suffered throughout the season) were calculated for athlete exposures, reported per 1000 athlete exposures. Overall injury prevalence was also calculated. Injury prevalences were also grouped by elbow, shoulder, as well as TL1-6, TL7-27, and TL28. Injury rate and prevalence 95% confidence intervals were determined through 2000 bootstraps.[42] Count data with a zero outcome were calculated through the Clopper-Pearson method.

Primary and Sensitivity Analyses

A Cox proportional hazards analysis was performed to determine the association between neck range of motion and arm injuries in professional baseball pitchers. A hazard ratio (HR) denotes the instantaneous rate of injury at a given time point. Hazard risk ratios with 95% CI's were reported. Cox survival models controlled for pitching role (i.e., starter versus reliever),[10] throwing arm dominance,[10] number of pitching appearances,[14,22] innings pitched,[6] fastball pitching velocity,[27-29] and the difference between dominant and non-dominant shoulder internal rotation.[7] To reduce risk of Type 1 error (i.e., false discovery rate), the Benjamini-Hochberg method was performed. A sensitivity analysis included only right-handed dominant pitchers. All analyses were performed in R version 4.02 (R Core Team (2013). R: A language and environment for statistical computing, using the *dplyr* package for cleaning and coding, the survival package for survival analyses, and the *survminer* and *ggplot2* packages for data visualization.

All statistical code can be obtained through the Open Science Framework link (https://osf.io/ha5qk/). Due to agreements with the MLB organization, no data, nor synthetic, data can be shared.

Results

A total of 91 pitchers were assessed at the beginning of spring training. Excluding those that were released in Spring training, and pitchers never activated from the injured list, 88 pitchers were included (Table 1; Appendix 2). Pitchers that suffered an arm injury and those that did not demonstrated similar age, body mass, innings pitched, and pitch velocity. Injured pitchers exhibited descriptively decreased shoulder internal rotation and increased external rotation.

Of the 88 included pitchers, the average number of exposure days for pitchers who suffered an arm injury was 73 (47) days and 174 (48) days for pitchers that did not suffer an arm injury. A total of 15,942 athlete exposure days were collected over the course of the MiLB season.

Neck Range of Motion Clinical Findings

Neck range of motion values for professional baseball pitchers are reported in Table 2.

Arm Injury Epidemiological Findings

A total of 20 arm injuries were suffered by pitchers during the minor league baseball season. Similar injury prevalence was observed for shoulder and elbow injuries (Table 3).

Neck Range of Motion Prognostic Factors

In pitchers who suffered an arm injury, for every degree increase in the difference between dominant versus non-dominant neck rotation, there was a four-fold increase in hazard (HR: 4.0; 95% CI: 1.1, 13.9, p = 0.041; Figure 2). There was no difference in injury hazard in the difference between the dominant and non-dominant CFRT (HR: 1.00; 95% CI: 0.9, 1.1, p = 0.999). There was no difference in injury hazard in the difference between dominant and non-dominant neck lateral flexion (HR: 1.0; 95% CI: 0.9, 1.1, p = 0.733).

Sensitivity Analyses

Results were similar for difference in dominant versus non-dominant neck rotation hazard (HR: 3.8; 95% CI: 1.1, 13.5, p = 0.053). Similar results were observed for hazard in the difference between dominant and non-dominant CFRT (HR: 1.00; 95% CI: 0.9, 1.1, p = 0.999) and hazard in the difference between dominant and non-dominant neck lateral flexion (HR: 1.0; 95% CI: 0.9, 1.1, p = 0.793).

Discussion

Pitchers with decreased dominant compared to non-dominant neck rotation had increased arm injury hazard. The sample data demonstrated similar shoulder range of motion[7,10] and arm injury rates[41,46] compared to previous literature, suggesting a generalizable professional baseball pitcher sample. These data suggest that cervical dysfunction may have influence on shoulder and elbow injuries in professional baseball pitchers.

Neck flexion, extension, lateral flexion, and rotation demonstrated similar range of motion measurements compared to previous literature in collegiate baseball pitchers.[16] Neck flexion and rotation range of motion increases during development, with stabilization after the end of growth and development.[1] As baseball has relatively small risk of collision and head and neck injuries,[4,13] neck range of motion should be stable across collegiate and professional baseball pitchers. However, the CFRT demonstrated greater range of motion values compared to previous literature.[16] The CFRT is purported to assess upper cervical mobility, particularly providing ligamentous tension to isolate atlantoaxial joint motion.[3] Potential explanations for dissimilarities between collegiate and professional normative values may be due to reduced skill in performing this test causing systematic differences in range of motion value, differences in ligamentous laxity, or greater access to sport medicine manual therapy. However, further studies are required to evaluate the precision and stability of this result across other clinicians and professional baseball pitcher samples.

Pitchers who suffered an arm injury demonstrated significantly greater difference in dominant versus non-dominant neck rotation compared to uninjured pitchers. Previous research in Japanese baseball players have found limitations and asymmetry in neck range of motion on the dominant side to be an arm injury prognostic factor, further supporting these findings. [48] Reduced neck rotation may reduce a pitcher's ability to maintain gaze during the pitching motion. Compensatory pitching movements may be enacted to maintain gaze on the target, particularly during trunk rotation.[16] Early trunk rotation and increased lateral trunk tilt have both demonstrated increased elbow varus torque during the pitching motion and subsequent increased arm injury risk.[8,9] Another potential explanation is decreased neck rotation can decrease the interforaminal cervical space during pitching, reducing the afferent scapular and glenohumeral neuromuscular strength and control.[24] This would reduce periscapular, shoulder, and elbow stability and control, potentially increasing kinetics to the shoulder and elbow joints.[8] However, currently the mechanisms underlying these associations are unknown. Precise randomized controlled trials are required to evaluate the mechanisms and risk reduction effectiveness of intervening on these neck clinical factors.

As with all studies, there were limitations. Neck range of motion was only measured in spring training. As range of motion measures can change throughout the season, neck range of motion values may be different for mid and late season assessments. While shoulder range of motion was controlled in all models, other clinical factors throughout the kinematic chain may modify arm injury risk,[11] decreasing the precision of these analyses. Pitch count, pitching appearances, and pitch velocity were counted and controlled for in analyses. However overall throw counts were not recorded, decreasing the precision of these analyses. Pitching biomechanics were not assessed in this study, decreasing the generalizability of these findings across different pitching motions. This study included one season of data, decreasing the size, and potential validity and significance of the findings. No *a priori* sample size calculation was performed, decreasing the ability to ascertain the risk of Type two error. Due to the small sample and no *a priori* sample size calculation performed, as a result non-significant differences could be the result of inadequate power to detect a difference. The random variance in sampling may decrease the generalizability of these results across baseball players at all competition levels.

Conclusions

Decreased dominant compared to non-dominant neck rotation demonstrated a strong positive arm injury hazard, suggesting generalizability across high level baseball pitchers. However, the Cervical Flexon-Rotation Test did not have prognostic value in this sample. Future research is needed to evaluate the efficacy of intervening on neck range of motion to reduce arm injury risk in baseball pitchers.

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Legends to Figures

Figure 1. Description of Limitations of Neck Range of Motion and Potential for Increased Shoulder and Elbow Injury

Figure 2. Survival Probability of Professional Pitchers Concerning the Difference in Dominant and Non-Dominant Neck Rotation Over the Course of a Minor League Season

<Table 1. Pitcher Descriptive Statistics>

<Table 2. Neck Range of Motion Measurements and Comparison of Injury and Non-Injured Professional Baseball Pitchers>

<Table 3. Pitcher Injury Characteristics>

Table 1. Pitcher Descriptive Statistics

Variable	All Pitchers (n = 88)	Pitchers that did not Suffer an Arm Injury (n = 68)	Pitchers that Suffered an Arm Injury (n = 20)
Age (years)	24 (2)	24 (2)	23 (2)
Body Mass Index (kg/m^2)	25 (2)	25 (2)	25 (2)
Hand Dominance (%Left)	21 (23%)	18 (26%)	2 (10%)
Starter (%)	28 (31%)	20 (29%)	8 (40%)
Pitching Appearances	22 (14)	24 (13)	16 (11)
Innings Pitched	45 (27)	46 (27)	41 (27)
Average Fastball Velocity (mph)	92 (2)	93 (2)	92 (2)
Shoulder Clinical Measurements			
Dominant Shoulder External Rotation (°)	133 (19)	132 (20)	134 (15)
Non-Dominant Shoulder External Rotation (°)	121 (19)	122 (19)	120 (20)
Dominant Shoulder Internal Rotation (°)	37 (11)	39 (11)	34 (13)
Non-Dominant Shoulder Internal Rotation (°)	46 (13)	45 (13)	52 (9)
Dominant Shoulder Horizontal Adduction (°)	11 (13)	12 (13)	10 (12)
Non-Dominant Shoulder Horizontal Adduction (°)	24 (10)	23 (10)	28 (11)
Dominant Shoulder Humeral Torsion (°)	4 (13)	5 (13)	5 (11)
Non-Dominant Shoulder Humeral Torsion (°)	23 (15)	23 (15)	25 (14)

Data are reported as mean (standard deviation) for continuous variables and count (%) for count data

Table 2. **Neck Range of Motion Measurements and Comparison of Injury and Non-Injured Professional Baseball Pitchers.**

Neck Range of Motion Variable	All Pitchers (n = 88)	Pitchers that did not Suffered an Arm Injury (n = 68)	Pitchers that Suffer an Arm Injury (n = 20)
Flexion (°)	64 (10)	64 (10)	64 (13)
Extension (°)	69 (11)	69 (10)	69 (12)
Dominant Lateral Flexion (°)	39 (8)	49 (8)	36 (9)
Non-Dominant Lateral Flexion (°)	40 (8)	40 (8)	38 (7)
*Difference in Lateral Flexion (°)	-1 (7)	-1 (7)	-2 (7)
Dominant Neck Rotation (°)	77 (9)	78 (9)	74 (8)
Non-Dominant Neck Rotation (°)	79 (8)	79 (8)	79 (8)
*Difference in Neck Rotation (°)	-2 (9)	-1 (9)	-5 (8)
Dominant Cervical Rotation Test (°)	61 (8)	62 (7)	61 (9)
Non-Dominant Cervical Flexion-Rotation Test (°)	62 (7)	62 (7)	61 (7)
*Difference in Cervical Flexion-Rotation Test (°)	-1 (7)	-1 (6)	-1 (10)

Data are reported as mean (standard deviation)
*Difference is calculated as the difference between dominant and non-dominant side. A positive value indicates the dominant side demonstrated greater degrees, while a negative value indicates the dominant side demonstrated smaller degrees compared to the non-dominant side.

Table 3. Pitcher Injury Characteristics

Injury	All Pitchers (n = 88)
Arm Injury Rate (per 1000 exposure days)	1.3 (95% CI: 0.7, 1.7)
Arm Injury Prevalence	20 (23%; 95% CI:14, 33)
Mean Days Lost from Non-Contact Arm Injury	50 (39)
Grouped Elbow and Shoulder	
Elbow Injury	11 (13%; 95% CI: 6, 21)
Shoulder Injury	9 (10%; 95% CI: 5, 19)
Injury Severity	
Arm Injury Time Loss 1-7 Days	3 (3%; 95% CI: 1, 10)
Arm Injury Time Loss 8-27 Days	7 (8%; 95% CI: 3, 16)
Arm Injury Time Loss 28+ Days	10 (11%; 95% CI: 6, 20)

Data are reported as mean (standard deviation) for continuous data and count (%) for count data
Injury rate and injury prevalence confidence intervals were calculated through 2,000 bootstraps
Prevalence confidence intervals with 0 counts were calculated through the Clopper-Pearson Method
NA = Not Applicable

A. Deficits in neck rotation may change a pitcher's ability to maintain gaze on the target from front foot contact through acceleration, altering pitching mechanics.

B. Deficits in extension and rotation may change a pitcher's ability to maintain gaze on the target from acceleration through follow through, altering pitching mechanics.

Figure 1. Description of Limitations of Neck Range of Motion and Potential for Increased Shoulder and Elbow Injury

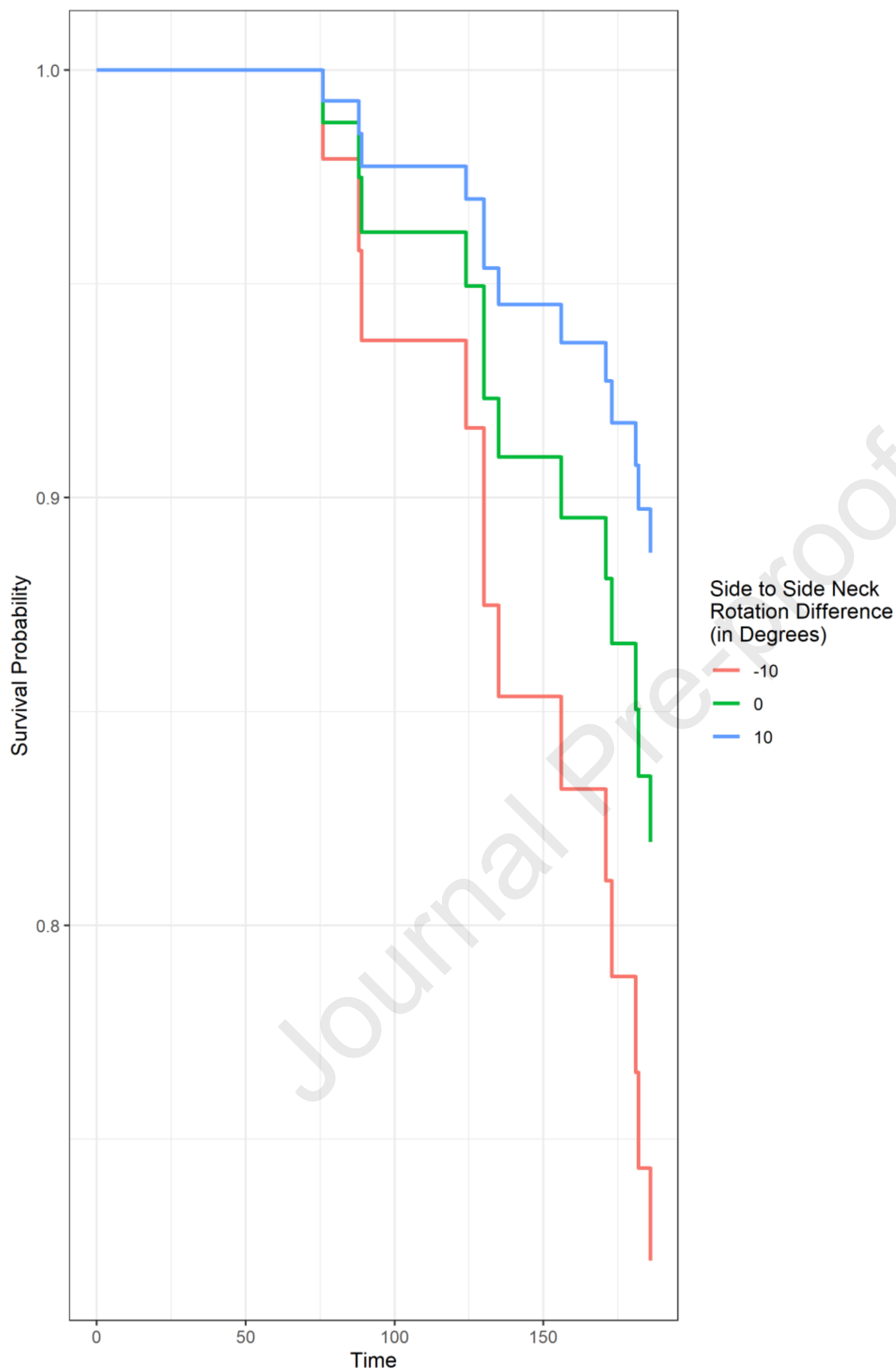

Figure 2. Survival Probability of Professional Pitchers Concerning the Difference in Dominant and Non-Dominant Neck Rotation Over the Course of a Minor League Season