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The Influence of Shoe and Cleat Type on Lower Extremity Muscle Activation in Youth Baseball Pitchers

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ABSTRACT

Background: Baseball pitching is a dynamic movement where the lower extremities generate and sequentially transfer energy to the upper extremities to maximize ball velocity. The need for lower body muscular strength to produce adequate push-off and landing forces has been documented; however, the influence footwear and surface inclination has on muscle activation remains unknown. **Objectives:** Determine how pitching in molded cleats and turf shoes from a pitching mound and flat ground affects stride-leg muscle activation in youth baseball pitchers while determining percent activation during each pitching phase. **Methods:** Cross – sectional study analyzing mean muscle activity and percent activation of the vastus medialis, semitendinosus, tibialis anterior, and medial gastrocnemius on the stride-leg of 11 youth baseball pitchers when pitching fastballs. **Results:** Footwear did not significantly alter vastus medialis or semitendinosus muscle activation ($P > 0.05$). The turf shoe x pitching mound interaction elicited significantly ($P < 0.05$) greater mean muscle activity in the medial gastrocnemius and tibialis anterior from stride foot contact to maximum glenohumeral internal rotation. Molded cleats produced greater activation levels in the tibialis anterior on flat ground from stride foot contact (0.374 ± 0.176 mV) to ball release (0.469 ± 0.150 mV). **Conclusion:** Findings suggest footwear significantly alters the activity level of the ankle stabilizing musculature. Youth baseball pitchers and coaches should be cognizant of what footwear is worn on a pitching surface. Maximal activation of the tibialis anterior and medial gastrocnemius can ensure the stride leg is adequately stabilized to absorb the momentum generated by trail leg.

Key words: Shoes, Baseball, Electromyography, Lower Extremity, Muscles, Adolescent

INTRODUCTION

Baseball pitching is a complex motion that requires the synchronized action of the lower and upper extremity musculature to produce a throw at or near maximal velocity. While the summation of speed principle has universally been used to describe the segmental motion needed to produce a given ball velocity, Neal et al. (1991) suggests individual differences such as throwing style, skill level, and the effect of ball weight also be considered. Fundamentally, a segment begins movement when its adjacent, proximal segment reaches its maximum angular velocity (Putnam, 1993). Maximal activation of the lower extremity musculature is therefore pivotal in generating enough energy to transfer up the kinetic chain to produce a desired ball velocity. This is evidenced by the fact push-off and landing ground reaction forces are correlated with arm velocity indicating the more force a pitcher can generate from their lower body, the faster they could potentially pitch (MacWilliams et al., 1998; McNally et al., 2015).

The entire pitching movement has been previously separated into 6 traditional phases (Dillman et al., 1993; Werner et al., 1993). Electromyographic (EMG) activity has been studied in these phases within the upper extremity (DiGiovine et al., 1992; Gowan et al., 1987; Jobe et al., 1984; Jobe et al., 1983; Seroyer et al., 2010; Smidebush et al., 2019; Townsend et al., 1991), as well as the trunk musculature (Watkins et al., 1989); however, only two known studies (Campbell et al., 2010; Yamanouchi, 1998) have analyzed the lower extremity. Yamanouchi (1998) was one of the first to analyze lower-extremity muscle activity throughout the pitching cycle, but muscles of interest were categorized into groups based on their joint action and the pitching motion was divided into two phases. It was concluded that the adductors, quadriceps,

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and tibialis anterior play a pivotal role in conserving energy, controlling trunk sway, and decelerating the upper extremities to limit injuries. A more recent study reported mean EMG percentages of lower-extremity muscles in four phases and found the stride-leg (contralateral to the throwing arm) and trail leg (ipsilateral to the throwing arm) reached ‘very high’ activation levels during a baseball pitch (Campbell et al., 2010). This supports the need for athletes and coaches to prioritize lower body strength and endurance training for pitchers considering some may throw up to 30 pitches per inning or 100 pitchers per game (Campbell et al., 2010).

Surface composition and condition reports are obtainable for various collegiate and professional baseball fields while no such information is present for youth fields. Nonetheless, artificial surfaces are low-maintenance and cost effective creating an increase in popularity and usability for fields, bullpens, and batting cages. Approximately 25% of youth baseball players compete as pitchers (Lyman & Fleisig, 2005) allowing the opportunity for them to throw from various surface inclinations in a single game. It is within the rules for Little League players to remain in the game at another position if they are removed from the mound as a pitcher. If desired, players can change their footwear pre- and mid-competition to account for playing surface inclination. Pitching from a mound has shown to elicit kinematics changes in adolescent pitchers (Nissen et al., 2013). Shoulder and elbow moments increase by 6% when pitching from a mound, but the most notable differences were in the lower extremity. Stride-foot ankle plantarflexion was greater on a pitching mound (PM) causing an increase in knee extension due to the delay in foot contact (Nissen et al., 2013). To date, only one study has investigated how surface inclination and footwear effect youth pitching mechanics which concluded turf shoes (TS) increase stride-leg ankle plantarflexion due to the absence of studs that can penetrate the underlying surface (Gdovin et al., 2019); however, there is little understanding how the interaction between footwear and surface inclination affects lower extremity muscle activation.

The effectiveness of cleated footwear is determined by its ability to penetrate the underlying surface, which is affected by the surfaces’ hardness and shoe stud shape, and generate traction (Driscoll et al., 2015). Changing footwear on various playing surface inclinations may, consequently, alter muscle activation and subsequently the pitching movement. Therefore, the purposes of this study were to: [1] determine how pitching in molded cleats (MC) and TS from a PM and flat ground (FG) affects lower extremity muscle activation in the vastus medialis, semitendinosus, tibialis anterior, and medial gastrocnemius on the stride-leg of youth baseball pitchers and [2] define the percent activation of those muscles in each pitching phase. The first hypothesis (H_1) predicted that TS will produce larger EMG values in the vastus medialis and semitendinosus on both a PM and FG due to a sliding foot strike while the second hypothesis (H_2) predicted the MC will elicit an increase in tibialis anterior and medial gastrocnemius activation due to the cleat interlocking with the underlying surface.

METHODS

Participants and Study Design

A cross-sectional study design was deployed to evaluate eleven healthy right-handed, youth male baseball pitchers (Table 1) who voluntarily enrolled in the institutional review board approved study. In order to meet the necessary requirements to participate, all participants had to be between the ages of 10 and 15, have a minimum 2 years of competitive pitching experience, and have worn their baseball-specific footwear for a minimum of 1 hour per week during that timeframe. After informed consent and assent were obtained, a physical activity readiness questionnaire (PAR-Q) was completed to screen for musculoskeletal, orthopaedic, and cardiovascular abnormalities. Participants were excluded if they had any upper/lower body orthopedic or musculoskeletal injury within 6 months of data collection. Dependent variables of interest include mean muscle activity and percent activation of all four lower extremity muscles while the two types of footwear and surfaces are the independent variables.

Footwear

Metal cleats, MC, and TS are the three primary types of baseball cleats. The official rules of Little League-level baseball does not allow those between the ages of 4-12 years to compete in metal cleats (Little League, 2020). Therefore, due to the cohort’s age range, only MC and TS were utilized for data collection. The experimental procedures were completed in each participant’s personal MC and TS (Figure 1). Participants owned and utilized both types of footwear throughout their competitive baseball season. Footwear characteristics are listed in Table 2 with the average shoe size being 10.7 (U.S. sizing).

Table 1. Participant demographic data

	Mean	±SD	Minimum	Maximum
Age (years)	13.2	1.7	10.0	15.0
Height (cm)	170.0	15.7	149.6	193.2
Mass (kg)	61.0	14.7	40.7	86.7
Shoe Size (US)	10.7	2.5	7.5	14.0

Figure 1. Athletic Footwear Worn by Participants: Top Row: New Balance 4040v3 Low Youth Baseball Cleat (MC); Bottom Row: New Balance 4040v3 Turf Shoe (TS)

Surfaces

A 1.83 m x 4.27 m flat strip of 34 mm monofilament synthetic turf with a Styrene-Butadiene Rubber infill was placed in the center of the motion capture volume. Additionally, a portable PM (Proper Pitch Mounds, Garner, NC, USA) meeting Little League specifications was used.

Procedures

The experimental testing session began by obtaining participant anthropometrics. Participants were then prepped for MVICs following SENIAM guidelines (Hermens et al., 2000). The skin over the muscle belly of the vastus medialis, semitendinosus, tibialis anterior, and medial gastrocnemius was shaved, abraded, and cleaned prior to applying silver/silver chloride monopolar disposable surface electrodes (EME Company, Baton Rouge, LA, USA) on the stride-leg. A ground electrode was placed on the tibial tuberosity. Surface electromyography (EMG) was recorded at 1000 Hz using an 8-channel Noraxon Telemyo DTS 900 system (Noraxon USA, INC, Scottsdale, AZ, USA) synced with Vicon Nexus (Oxford, UK) motion capture software.

Three, five-second barefoot MVIC trials separated by 30 s were completed for each muscle of interest and were obtained during knee flexion (semitendinosus), knee extension (vastus medialis), dorsiflexion (tibialis anterior), and plantarflexion (medial gastrocnemius) (Allen et al, 2016; Donahue et al., 2019; Wilson et al., 2018). Knee flexion and extension had participants pull and push, respectively, into a padded weight bench with a leg attachment. Dorsiflexion MVICs were obtained by securing a strap around the junction of the toe phalanges and metatarsals and asking participants to maximally dorsiflex their ankle. Plantarflexion MVICs had participants stand with nominal knee flexion and press their toes into the ground with as much force as possible mirroring an isometric body-weight calf raise.

Following the protocol previously described by Gdovin et al. (2019), participants wore a compression shirt with markers Velcroed to upper extremity and trunk anatomical landmarks while the lower extremity and foot markers were placed on the skin and shoe, respectively, to identify the phases of interest. A plug-in-gait full body marker set was used and pitching motion was recorded and analyzed via a Vicon Nexus 3D motion capture system with 8 wall-mounted, infrared T-series cameras collecting at 240 Hz. The order of footwear and surfaces consisted of four counterbalanced conditions (MC x FG, MC x PM, TS x FG, TS x PM). The laboratory coordinate system was a right-handed reference frame with its axes defined as X_1, Y_1, and Z_1. X_1 is a vector directed from the pitching rubber to home plate, Z_1 is a downward vertical projection, and Y_1 is a cross product of X_1 and Z_1.

Table 2: Footwear characteristics

	Molded Cleat (MC)	Turf Shoe (TS)
Mass (kg)	0.3	0.3
Total # of Studs	18.0	n/a
Stud height (cm)	1.1	n/a

Each participant completed their personal warm-up routine, including stretching and non-throwing drills, with no time constraint (Fleisig et al., 1995; Werner et al., 1993). Participants pitched four-seam fastballs with the same technique and effort as if it were a game situation. A total of ten pitches were thrown from the stretch position, separated by 30 s of rest, into a net ten feet away with a designated strike zone ribbon. A 10 min. rest between footwear conditions acted as a washout period as an attempt to mimic the time between innings. The same experimental protocol was repeated for the three remaining counterbalanced conditions.

Data Analysis

The first three pitches without marker obstruction in each condition were used in the analysis (Gdovin et al., 2019; Nissen et al., 2007; Nissen et al., 2013; Solomito et al., 2015). All EMG data were collected throughout the entire pitch sequence and was broken down into the four phases of interest: stride foot contact (SFC), maximum glenohumeral external rotation (MER), ball release, maximum glenohumeral internal rotation (MIR) (Nissen et al., 2013; Oliver & Keeley, 2010). All phases were identified using customized Statistical Analysis System, version 9.3 (SAS Institute, Cary, NC, USA) models beginning with SFC (0%) and ending with MIR (100%) of the throwing arm. SFC was defined as the instance the foot, heel, or toe touched the ground. MER was measured in a plane perpendicular to the humerus as the greatest angle between the trunk's anterior and the forearm's distal direction (Fleisig et al., 1996) while ball release was defined as when one of the two markers placed on the baseball was 2 cm or greater away from the marker on the throwing hand (Nissen et al., 2007; Nissen et al., 2013). MIR was measured from the time of ball release until completion of the pitching motion.

Raw EMG data of the vastus medialis, semitendinosus, tibialis anterior, and medial gastrocnemius were smoothed using a fourth-order, zero-lag Butterworth filter (15 Hz) and full wave rectification preceded analysis. Mean MVIC was acquired by averaging the amplitudes across the middle 3 s within each 5 s trial. Similar to Campbell et al., (2010), the 1st and 5th s of each MVIC trial was eliminated to allow participants 1 s to reach their maximal contraction ("ramping up") while avoiding fatigue ("ramping down"). The three MVIC trials were then averaged together to produce a mean value per muscle that was used to calculate mean muscle activity in all four shoe-surface conditions within all four pitch phases. Mean muscle activity was calculated as the mean amplitude at SFC, MER, ball release, and MIR for the three analyzed pitches. A total of 5 data points were used on either side of the points of interest at each pitch phase. Percentages of MVIC were calculated by dividing the mean muscle activity from each lower extremity muscle during each of the four phases by the mean MVIC of the corresponding muscle (Campbell et al., 2010). No statistical analysis was run on this variable because the purpose was to provide descriptive data, which is comparable to the methods of Campbell et al. (2010). Mean EMG activation was classified based on the following criteria: minimal activity (0-20% MVIC), moderate activity (20-35% MVIC), moderately strong (35-50% MVIC), and significantly high (>50% MVIC) (Campbell et al., 2010; Tucker et al., 2005).

Statistical Analysis

Individual data sets were averaged across all participants to compare means between each shoe-surface condition. A 2x2 [2 Surfaces (FG, PM) x 2 Footwear (TS, MC)] repeated measure analysis of variance was used to analyze mean muscle activity and mean MVIC. When main effect significance was found, a Bonferroni post-hoc adjustment was used to compare simple main effects. If an interaction was seen in the ANOVA results, a univariate post hoc t-test was conducted. Mean MVIC's were analyzed using the SPSS 21 statistical software package (IBM SPSS® Statistics V21.0, Armonk, NY, USA) while mean muscle activity during the four phases of interest was conducted using Stata, version 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC, USA). An a priori alpha level was set at 0.05 for all analyses.

RESULTS

There were significant intra-class correlation coefficients (ICC) for pitch velocity (Table 3) but no significant differences were found ($F_{1,10}$ = 2.424, P = 0.15, = 0.195). No significant differences (P > 0.05) were found for the vastus medialis or semitendinosus in any of the four shoe-surface conditions during the four pitch phases; however, percent activation for both muscles would be classified as 'significantly high' except in the TS x FG condition at SFC where both muscles were 'moderately strong'. Results for the stride-leg medial gastrocnemius and tibialis anterior are broken down by pitch phases (Tables 4 and 5).

Stride Foot Contact

Significant differences were present at stride-leg foot contact in the medial gastrocnemius and tibialis anterior. Mean muscle activity in the medial gastrocnemius was significantly greater ($F_{1,10}$ = 4.967, P = 0.002, = 0.398) in TS on both the PM and FG generating 0.138 ± 0.065 mV and 0.130 ± 0.043 mV, respectively. While the tibialis anterior produced significantly greater values ($F_{1,10}$ = 4.012, P = 0.002, = 0.372) in the TS (0.394 ± 0.126 mV) on the PM, mean muscle activity in the MC (0.374 ± 0.176 mV) was significantly greater on the FG. Percent activation is classified as 'significantly high' for the medial gastrocnemius in all four shoe-surface conditions while the tibialis anterior was 'moderately strong' in all conditions except the TS x PM.

Table 3. Ball velocities

Variable	Mean	SD	ICC	*P*-Value	Confidence Intervals	
					Lower Bound	Upper Bound
Pitch Velocity (m/s)						
MC x FG	28.9	4.6	0.984	<0.001	0.959	0.995
MC x PM	28.7	4.5				
TS x FG	28.2	4.2				
TS x PM	28.3	4.5				

MC = molded cleat, TS = turf shoe, FG = flat ground, PM = pitching mound

Maximal External Rotation

Significant differences were present in the stride-leg medial gastrocnemius ($F_{1,10}$ = 4.849, P = 0.003, = 0.327) and tibialis anterior ($F_{1,10}$ = 3.419, P = 0.008, = 0.286) at the time of maximum glenohumeral external rotation. Both muscles produced significantly greater values in the TS (medial gastrocnemius: 0.146 ± 0.048 mV; tibialis anterior: 0.417 ± 0.196 mV) on the PM while activation in the MC (medial gastrocnemius: 0.394 ± 0.056 mV; tibialis anterior: 0.394 ± 0.185 mV) was significantly greater on the FG. The percent activation was 'significantly high' for the medial gastrocnemius throughout all shoe-surface conditions while the tibialis anterior was 'significantly high' for TS x PM and MC x FG while being 'moderately strong' in the TS x FG and MC x PM conditions.

Ball Release

Significant differences were present in the stride-leg medial gastrocnemius ($F_{1,10}$ = 5.243, P = 0.007, = 0.312) and tibialis anterior ($F_{1,10}$ = 4.932, P = 0.007, = 0.301) upon ball release. Mean muscle activity in the medial gastrocnemius was significantly greater in TS on both the PM and FG generating 0.168 ± 0.079 mV and 0.157 ± 0.074 mV, respectively. The tibialis anterior produced significantly greater values in the TS (0.479 ± 0.225 mV) on the PM while activity in the MC (0.469 ± 0.150 mV) was significantly greater on the FG. Percent activation classified both muscles as 'significantly high' throughout all four shoe-surface conditions.

Maximal Internal Rotation

Significant differences were present in the stride-leg medial gastrocnemius ($F_{1,10}$ = 6.689, P = 0.004, = 0.401) and tibialis anterior ($F_{1,10}$ = 8.324, P = 0.001, = 0.452) at the time of maximum glenohumeral internal rotation. Both the medial gastrocnemius and tibialis anterior elicited a significantly greater mean muscle activity in TS on both the PM (medial gastrocnemius: 0.219 ± 0.053 mV; tibialis anterior: 0.626 ± 0.213 mV) and FG (medial gastrocnemius: 0.195 ± 0.092 mV; tibialis anterior: 0.556 ± 0.261 mV). Percent activation classified both muscles as 'significantly high' throughout all four shoe-surface conditions.

DISCUSSION

The aims of the current study were to (1) determine how pitching in MC and TS from a PM and FG affects lower extremity muscle activation in the vastus medialis, semitendinosus, tibialis anterior, and medial gastrocnemius on the stride-leg of youth baseball pitchers and (2) establish the

Table 4. Mean muscle activity (mV)

Vastus Medialis	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**	***P*-Value**
SFC	0.295±0.124	0.277±0.130	0.301±0.141	0.318±0.149	0.610
MER	0.312±0.147	0.295±0.097	0.318±0.149	0.335±0.158	0.410
Ball release	0.358±0.168	0.335±0.158	0.329±0.086	0.399±0.187	0.220
MIR	0.468±0.211	0.416±0.196	0.428±0.201	0.445±0.209	0.280
Semitendinosus	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**	***P*-Value**
SFC	0.280±0.132	0.264±0.124	0.286±0.103	0.302±0.142	0.510
MER	0.297±0.139	0.295±0.132	0.302±0.097	0.319±0.150	0.690
Ball release	0.341±0.160	0.319±0.089	0.313±0.147	0.379±0.178	0.440
MIR	0.445±0.196	0.396±0.186	0.407±0.191	0.423±0.131	0.320
Medial Gastrocnemius	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**	***P*-Value**
SFC	0.138±0.065	0.130±0.043	0.114±0.054	0.114±0.053	0.002*[bcde]
MER	0.146±0.048	0.295±0.065	0.121±0.057	0.394±0.056	0.003* [bcde]
Ball release	0.168±0.079	0.157±0.074	0.125±0.015	0.143±0.067	0.007* [bcde]
MIR	0.219±0.053	0.195±0.092	0.163±0.076	0.159±0.035	0.004* [bcde]
Tibialis Anterior	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**	***P*-Value**
SFC	0.394±0.126	0.371±0.174	0.354±0.166	0.374±0.176	0.002*[bcde]
MER	0.417±0.196	0.294±0.126	0.374±0.176	0.394±0.185	0.008*[bcde]
Ball release	0.479±0.225	0.448±0.211	0.388±0.182	0.469±0.150	0.007*[bcde]
MIR	0.626±0.213	0.556±0.261	0.503±0.161	0.524±0.246	0.001*[abcde]

SFC = stride foot contact, MER = maximum external rotation, MIR = maximum internal rotation, TS = turf shoe, MC = molded cleat, PM = pitching mound, FG = flat ground

*Significance ($P < 0.05$) among footwear x surface.

Post-hoc comparisons: significant differences ($P < 0.001$) between [a]TS x PM & TS x FG, [b]TS x PM & MC x PM, [c]TS x PM & MC x FG, [d]TS x FG & MC x PM, [e]TS x FG & MC x FG, [f]MC x PM & MC x FG

Table 5. Muscle activation (% MVIC)

Vastus Medialis	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**
SFC	51.0	47.9	52.1	55.0
MER	54.0	51.0	55.0	58.0
Ball release	61.9	58.0	56.9	69.0
MIR	81.0	72.0	74.0	77.0
Semitendinosus	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**
SFC	50.9	48.0	52.0	54.9
MER	54.0	53.6	54.9	58
Ball release	62.0	58.0	56.9	68.9
MIR	80.9	72.0	74.0	76.9
Medial Gastrocnemius	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**
SFC	62.7	59.0	51.8	51.8
MER	66.4	134.1	55.0	179.1
Ball release	76.4	71.4	56.8	65.0
MIR	99.5	88.6	74.1	72.3
Tibialis Anterior	**TS x PM**	**TS x FG**	**MC x PM**	**MC x FG**
SFC	51.0	48.0	45.8	48.4
MER	53.9	38.0	48.4	51.0
Ball release	65.6	58.0	50.2	60.7
MIR	81.0	71.9	65.1	67.8

SFC = stride foot contact, MER = maximum external rotation, MIR = maximum internal rotation, TS = turf shoe, MC = molded cleat, PM = pitching mound, FG = flat ground percent activation of those muscles during each pitching phase. Results indicate that pitching in TS on a PM may lead to significantly greater muscle activation in the medial gastrocnemius and tibialis anterior throughout all four phases. MC produced significant muscle activation on FG from SFC to ball release in the tibialis anterior while the medial gastrocnemius was significantly active at MER. Results rejected the first hypothesis (H_1) which predicted TS would produce larger EMG values in the VM and ST on both surface inclinations; yet, the second alternative hypothesis (H_2) forecasting MC would elicit larger tibialis anterior and medial gastrocnemius activation levels was accepted.

Data from this investigation produced greater overall muscle activity compared to the original study (Yamanouchi, 1998) investigating lower-extremity muscle activation during a baseball pitch. While Yamanouchi (1998) concluded that the abductor and adductor musculature generates the primary source of power within the trail- and stride-legs producing over 80% MVIC, the vastus medialis, tibialis anterior, and medial gastrocnemius are the only muscles of interests that both studies analyzed and are therefore the only three that can be compared. Discrepancies between data can potentially be attributed to the breakdown of phases. Yamanouchi (1998) used two phases with the first including the 2 s prior to SFC; however, the pitcher is currently in their windup and in a period of single (trail)-leg support and one would intuitively hypothesize that the stride-leg musculature would not be as active since it has not made contact with the ground. This may explain the reported significant vastus medialis activation within this phase while the current study found no significant differences in either the vastus medialis or semitendinosus in any shoe-surface condition. Phase two included the 2 s time frame after SFC closely matching the time point of MER in the current study. Comparing these intervals show the percent muscle activation within the vastus medialis, tibialis anterior, and medial gastrocnemius were double than that reported by Yamanouchi (1998) in all shoe-surface conditions.

Campbell et al. (2010) divided the pitching cycle into four distinct phases and for comparison purposes, phases two, three, and four will be compared to the SFC, ball release, and MIR time points within the current study, respectively. The medial gastrocnemius activity was significantly high throughout all phases in both studies with Campbell et al. (2010) reporting larger values, which was not unexpected. Participants were skilled collegiate players who were an average of 9 years older and threw a minimum of 31.3 m/s (70 mph) compared to the youth athletes tested in the current study. In order for the youth pitchers to generate this required ball velocity, producing larger muscle contractions up the kinetic chain would be required. The vastus medialis activation levels were 'moderately high' in phase two while phases three and four demonstrated 'significantly high' activity (Campbell et al., 2010). Results from the current study showed 'significantly high' vastus medialis activity in all four phases; however, the collegiate athletes produced larger values. Campbell et al. (2010) attributed the large stride-leg vastus medialis activation levels, specifically in phase three, to its importance in controlling and stabilizing the knee joint while the trunk and upper extremity rotate about the hip. This may indicate that youth baseball pitchers need to focus on strengthening the vastus medialis and semitendinosus, regardless of the footwear and surface they play on, to provide support to the stride knee during arm deceleration and follow through.

Gdovin et al. (2019) previously revealed stride-leg ankle plantarflexion increases while wearing a TS on both a PM and FG which may be the reason for significantly high medial gastrocnemius muscle activity in the current study. Similarly, with shoulder external rotation angle, torque, and velocity increasing in TS (Gdovin et al., 2019), the medial gastrocnemius and tibialis anterior appear to provide enough foot and ankle stability to allow the glenohumeral ER velocity and torque to increase by 6% and 18%, respectively. It is interesting to note that the medial gastrocnemius and tibialis anterior continuously increase activity throughout the entire pitching cycle in all shoe-surface conditions. Immediately prior to SFC, the pitcher is in a period of single support with the stride-leg suspended in air indicating the athlete continuously activates this musculature to prepare for force absorption upon SFC. The continuous activation is not only advantageous for pitchers to generate large ground reaction forces at SFC to absorb the momentum generated by the trail leg, but it has also been shown to be a predictive measure of ball velocity (McNally et al., 2015). It is oftentimes thought that the muscle activation and ground reaction forces generated in the trail-leg are thought to play a large role in improving ball velocity, however, push off force and ball velocity are weakly correlated in high school pitchers (Oyama & Myers, 2018).

Significant interactions between footwear and surface exist for mean muscle activity for both the medial gastrocnemius and tibialis anterior. This suggests both MC and TS significantly influence the ankle stabilizing musculature during the pitch cycle. The mean muscle activity for the medial gastrocnemius was significantly greater throughout all four phases while wearing a TS on the PM and the TS x FG interaction produced the largest medial gastrocnemius activation except at MER. Similarly, the mean muscle activity for the tibialis anterior was significantly greater in a TS on a PM, but the MC elicited greater muscle activation on the FG except at MIR. This evidence suggests that the studs on the sole of the MC engage with the underlying surface restricting the motion occurring at the interface. This allows for pitchers to rapidly transition from a plantarflexed position at SFC to dorsiflexion shifting from medial gastrocnemius to tibialis anterior activity. Due to the TS inability to penetrate the underlying surface from its lack of studs, it causes a sliding foot strike and the footwear is displaced relative to the surface.

In conjunction with previously published literature, it does appear that controlling for footwear conditions with respect to the slope of the playing surface does have an impact on pitching outcome. Youth pitching kinematics have shown to increase the stress placed upon the upper extremity when pitching from a mound (Nissen et al., 2013) and wearing TS on FG (Gdovin et al., 2019). While stride length and pitching velocity remain consistent regardless of the footwear-surface condition, TS bring about greater changes in stride-leg ankle plantarflexion joint angles (Gdovin et al., 2019) and subsequently medial gastrocnemius muscle activity. This information provides youth baseball coaches and athletes evidence for strengthening the lower extremities, both uni- and bi-laterally, in order to maximize the generation and transfer of momentum in both types of footwear.

Despite novel findings on the implications footwear has on lower extremity muscle activation, all data were collected in a controlled laboratory setting creating limitations. First, the use of data on both the stride- and trail-leg would have provided insight as to how pitchers generate and utilize mechanical energy to begin their movement towards home plate as either a 'push off' or 'fall'; however, the use of a non-wireless EMG unit attached to both lower extremities would have potentially limited the stride length of participants and subsequently muscle activation. The stride-leg was chosen because muscle activation patterns in different footwear would attempt to explain previously reported kinematic changes in ankle plantarflexion (Gdovin et al., 2019; Nissen et al., 2013) and it is also responsible for resisting up to 72% of the shear forces generated from a pitcher's body weight (MacWilliams et al., 1998). Second, while a larger sample size would have been desired, previous studies were published and reported statistical and clinical significance with sample sizes ranging from 7 to 15 (Gdovin et al., 2019; Nissen et al., 2007; Yamanouchi, 1998). While the methodology was designed to control for and mimic game-like scenarios, game situations vary and controlling for some variables in a laboratory may not always be possible. Future studies should investigate the effect the shoe-surface interaction has on lower extremity co-contraction indices to determine joint stability throughout the pitching cycle.

CONCLUSION

This study demonstrates the importance footwear plays when youth baseball pitchers throw from various surface inclinations because muscle activation is significantly altered in the ankle-stabilizers (medial gastrocnemius and tibialis anterior) compared to the knee stabilizers (vastus medialis and semitendinosus). Pitching in TS on a PM produces 'significantly high' activation patterns in both the medial gastrocnemius and tibialis anterior throughout all phases of the pitching cycle. Similarly, MC elicited 'moderately to significantly high' tibialis anterior activation on FG from SFC to ball release. The practical implications of these findings suggest youth baseball pitchers and coaches should be cognizant of which footwear is worn on a pitching surface. Maximal activation of the medial gastrocnemius and tibialis anterior can ensure the stride leg is adequately stabilized to absorb the momentum generated by the trail leg.

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