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Lower Extremity Asymmetries and their Relationship to Pitching Ball Velocity and Bat Handle Velocity in College Baseball Athletes

Introduction

The sport of baseball has a reliance on unilateral force production but research regarding lower extremity asymmetries could provide better insight in improving on-field performance. Two measurements of lower extremity symmetry have been reported in the literature: the bilateral deficit (BLD) and the lower extremity symmetry index (LSI). The BLD is a phenomenon in which the summation of force production of two legs unilaterally is greater than the force production of both legs bilaterally (Škarabot, et al., 2016). A measure of this symmetry has been defined in the literature as the bilateral index (BI) and has been presented as: BI (%) = (100 x bilateral / (right unilateral + left unilateral) – 100) (Howard, J. D., & Enoka, R. M., 1991). The LSI is a measurement of the discrepancies between force producing capabilities of the lower extremities unilaterally. Limb symmetry has been calculated previously in the literature using the formula: LSI = (Non dominant leg force production/dominant leg force production x 100) (Ceroni, et al., 2012). Baseball athletes are required to transfer kinetic energy from a trail leg to a lead leg in both pitching and hitting scenarios. Both concentric and eccentric contractions occur in order to utilize the highest ground reaction forces possible. While there is no definitive understanding of the exact reason for the BLD, it may be simply explained by differences in force–velocity curves between unilateral and bilateral actions (Škarabot, et al., 2016). During pitching, the pitcher pushes off the rubber then proceeds to land with the lead leg which in turn transfers energy up the kinetic chain into the ball resulting in linear velocity. Additionally, hitters reproduce a similar movement by transferring weight from the trail leg into the lead leg with rotation of the torso in order to produce force into the ground which ultimately rotates the bat. With all of these significant lower extremity movements taken into consideration, it would be beneficial to further understand the relationship between the lower extremity symmetry and pitching velocity and bat handle velocity in collegiate athletes. In the game of baseball today, pitching ball velocities and bat handle velocity are two key performance indicators that professional and collegiate teams attempt to maximize. Therefore, the purpose of this proposed study is to examine the relationship between lower extremity asymmetry and its effects on-field performance.

Review of Literature

This paper will discuss two forms of lower extremity asymmetries: the bilateral deficit (BLD) and the lower extremity symmetry index (LSI). There are still no definitive answers as to the underlying mechanisms behind lower extremity asymmetry. Previous studies have suggested a few possibilities for BLD. Differences in shortening velocities between unilateral and bilateral movements could be a mechanical reason behind the deficit. Neurologically, the evidence suggests that a higher-order neural inhibition could be an influencing factor. Postural stability of testing subjects and their use of counterbalances could affect output during unilateral movements. Additionally, familiarity of the task has a significant influence on the presence of the bilateral deficit. (Rutherford & Jones, 1986). Furthermore, other evidence suggests that muscular adaptations are likely not the reason for the BLD (Carroll et al. 2006). Previous research points towards neurological factors as being the main cause of the BLD. Interestingly, there is evidence that unilateral strength training can produce significant adaptations in the untrained limb. This occurrence has been shown to be most prevalent with training that involves 3-5 sets of 8-15 repetitions of eccentric contractions with 1-2 minutes of rest time between sets (Cirer-Sastre, et al., 2017). While it is not certain as to why the BLD phenomenon occurs, it is necessary to address the possibilities starting with musculoskeletal activation and adaptations during unilateral and bilateral training movements.

Other research has been done addressing hypertrophic adaptations and musculoskeletal activation during unilateral and bilateral training. In one study, a unilaterally trained group increased adductor magnus and vastus medialis muscle volumes significantly more than the bilateral group while the bilateral group presented an increase in muscle volume of the vastus lateralis, vastus intermedius, and lateral gastrocnemius in comparison to the unilateral group (Núñez et al. 2018). When evaluating muscle activation in unilateral and bilateral movements, one study found that participants showed greater activation of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris and erector spinae during the bilateral squat compared to the unilateral squat (Eliassen, et al., 2018). While there seem to be differences in musculoskeletal activation and adaptations in unilateral and bilateral training, it is necessary to explore performance outcomes when training unilaterally or bilaterally.

Since the aim of this review is to examine how lower extremity asymmetry affects performance, it is necessary to examine unilateral and bilateral performance metrics. One study unsurprisingly found that both exclusively bilateral and exclusively unilateral groups showed significant improvements in 1RM strength in their respective interventions. Notably, both groups showed significant improvements in the alternative intervention as well. This study showed that there is likely an underlying connection between improving maximal strength of the lower extremities with no strict requirement for specific unilateral or bilateral training (Appleby, et al., 2019). When considering other performance metrics like change of direction and power, another study showed both unilateral and bilateral training groups decreased change of direction test times, but the unilateral group had superior results in the transition phase of the change of direction test. Both types of training increased barbell velocity, but the bilateral group had substantially higher improvements in the half squat power test (Núñez, et al., 2018). This contradicts other research showing that barbell velocity was significantly greater in a unilaterally trained group (Eliassen, et al., 2018). When considering movements that involve the stretch shortening cycle, both modalities of training improved countermovement jump performance but did not change 10m sprint times (Núñez, et al., 2018). While the consensus on unilateral and bilateral training is unclear, it is important to examine the presence of the BLD and how it affects performance in order to utilize maximal force producing capabilities.

Previous research on how the presence of the BLD affects performance has been unable to come to a conclusion on whether or not the BLD or lack thereof is beneficial for performance. In one study, Bishop and colleagues (2019) examined the presence of the BLD and showed that there was a relationship between increased presence of jumping BLD and change of direction performance. This research suggests that a presence of BLD may be advantageous when considering change of direction performance metrics. This was not the case for sprinting speeds. There was no significant correlation between BLD and 10m and 30m sprint times. Bishop and colleagues (2019) also found participants exhibited bilateral facilitation during the depth jump test but not the countermovement jump test. This finding can lead to the belief that explosive unilateral movements may be limited by some underlying factor. Interestingly enough, other research has shown that countermovement jump performance was not correlated with decreased presence of the BLD. In accordance with previous research, Psycharakis and colleagues (2019) found that there was an increased presence of BLD in countermovement jumps, another reactive movement, compared to the non-reactive squat jumps . Other research agrees with this suggestion showing that actions involving explosive force are more prone to reduced agonist neural drive than actions that involve maximal voluntary forces. The presence of the BLD in peak rate of force development has been reported to range from 0-24% (Psycharakis, et al., 2019). When considering evaluating force output within various musculoskeletal contraction types, other research has been performed measuring the discrepancy between unilateral and bilateral force production within isometric contractions. Alternatively, Bishop and colleagues utilized an isometric squat as opposed to an isometric mid-thigh pull (Bishop et. al, 2019). Finally, previous research in untrained subjects has shown that the BLD is present in trained and untrained subjects, even subjects that only perform weightlifting as their performance activity (Ebben, et al., 2009). Since traditional weightlifting is almost exclusively performed in the sagittal plane and displays less plyometric qualities in nature, research suggests that the BLD could be a result of natural variance.

When considering LSI, various studies have come to inconclusive and conflicting results regarding whether or not lower extremity asymmetries can hinder or improve performance. There is a general consensus that strength asymmetries greater than 10% are clinically significant and may result in decreased performance (Bishop, 2016; Bond, 2017). One study showed that female college athletes with greater than 15% lower extremity strength asymmetry were three times more likely to undergo an injury in comparison to their symmetric counterparts (Bond 2017). Similarly to BLD, the physiological underpinnings of LSI are unclear and may be multifaceted in nature. Asymmetries could result from muscular or neurological factors, and even compensatory neural patterns developed during task-specific outcomes (Wang, 2019).

Muscle force production capabilities are traditionally greater in the dominant limb than the non-dominant side, along with greater stability than the non-dominant side. (Wang, 2019). With the sport of baseball requiring force producing capabilities from both the dominant and non-dominant legs, this leads to further investigation of possible limiting strength factors. Since there are multiple strategies to assess lower extremity asymmetry, this paper will be utilizing a method comparing a dominant or “lead” leg (a left leg in the case of a right handed pitcher or hitter) and a non-dominant or “trail” leg (a right leg in the case of a right handed pitcher or hitter) (Bishop, 2016). One study examining lower extremity symmetry during functional tasks showed that in participants that demonstrated asymmetries, there was greater activation of the non-dominant limb agonist musculature and higher antagonist coactivation of the muscles of the dominant limb, suggesting more symmetrical force output during bilateral as opposed to unilateral tasks (Bond, 2017). While the origin of LSI may not be clear or necessarily finite, various studies have examined the relationship between strength asymmetry and desirable performance metrics.

Individuals both inside and outside of athletic performance tend to gravitate towards one side of the body being the dominant side. This propensity can be due to cerebral hemisphere dominance in the brain (Kaçiglu, 2019). Since ambidexterity is only present in roughly one percent of the population, this cerebral dominance may be a contributing factor in athletic performance asymmetry (Kaçiglu, 2019). The sport of baseball and the movement of pitching and hitting require both high absorptive and generative forces from the strength of the lower extremity muscle groups, which is essential to maximize desirable velocity metrics (Kaçiglu, 2019). Studies have shown that high levels of asymmetry can increase risk of injury and even reduce athletic performance (Kaçiglu, 2019). Conversely, some research has shown that high strength asymmetry can be beneficial for performance in change of direction tests (Kaçiglu, 2019). With movements like the pitching delivery and the hitting swing, there may be a potential advantage for the presence of strength asymmetries. One study showed that inter-limb asymmetries had no significant effect on concentric, dynamic, and accelerative performance in physically active but not highly trained individuals (Kaçiglu, 2019). Since highly trained athletes adapt to the specific demands of their task, a population that is not highly trained may not present comparable performance metrics in comparison to their highly trained counterparts. Another study found that there is a negative correlation between vertical jump height and isometric force production asymmetry (Bailey, 2013).

While some research suggests that BLD and LSI can influence both performance decrements and increases, the origins and the benefits, or lack thereof, of the presence of BLD and LSI are still unclear. It is necessary to administer a test to evaluate maximal unilateral and bilateral lower extremity strength that is similar to the requirements of the mechanics of the pitching delivery and the hitting swing. Both the bilateral isometric mid-thigh pull and unilateral isometric mid-thigh pull assess maximal strength in relatively similar joint angles as pitching and hitting.

Biomechanics and kinetics of the pitching delivery

While each pitcher has their own unique biomechanics during pitching, the mechanical requirements of the pitching delivery require significant forces from both the upper and lower extremities, transferring of energy through the kinetic chain, and nearly irreproducible sequential timing. An in-depth pioneer study analyzing biomechanics of the pitching delivery by Pappas

(1985) broke down the pitching movement into three phases: the cocking phase, acceleration phase, and follow-through phase.

The cocking phase begins when the pitcher makes their first movement from the mandatory stationary point on the pitching rubber and ends when the shoulder is in the greatest degree of external rotation. The cocking phase is utilized in order to store the greatest potential energy to maximize velocity of the baseball when released. The movement occurs in roughly 1.5 seconds. Given the rapid force production requirements, both the unilateral and bilateral isometric mid-thigh pulls were deemed appropriate to evaluate maximal strength asymmetries. The cocking phase progresses when the leg contralateral (trail leg) to the pitching arm pushes off the rubber in order to move the body's center of gravity towards the direction of home plate where the ball is being thrown. The moment the trail leg is no longer touching the rubber, three movements occur simultaneously resulting in a transfer of energy from the trail onto the lead leg. Both arms flex forward, the trail leg and the torso rotate roughly 90 degrees, and the hip above the trail leg along with the trail knee flex. This influences the lead leg to flex slightly in order to accept the forces produced from the trail leg and the ground. Then, the movement most similar to the unilateral isometric mid-thigh pull occurs. The knee of the lead leg forcefully extends along with ankle plantar flexion and aggressive knee and hip extension influencing the center of gravity to accelerate toward the desired direction. The center of gravity then rotates forward, resulting in rotation of the shoulders, known as "hip and shoulder separation". The lead leg finishes its descent left or right of the body's midline, resulting in maximal counter rotation of the pelvis and trunk. While the acceleration phase and the follow-through phase are elements of the pitching delivery, the most significant lower extremity forces have already occurred in the cocking phase and will not be discussed in this paper.

Since there is both rapid and high magnitude force production and absorption during the pitching delivery, the immediate and immense force production of the isometric mid-thigh pull was chosen to address lower extremity strength asymmetries. Previous research has shown the biomechanical requirements of the pitching delivery, but further research is necessary to determine the force producing requirements of both the trail and lead legs. While not identical, the hitting motion requires similar force producing and rotational qualities as the pitching delivery.

Biomechanics and kinetics of the swing

Much like the pitching delivery, previous studies have divided the swing into pre-determined sequences: Foot off, foot down, and ball contact (Welch, 1995). Foot off begins when the lead leg disconnects from the ground and initiates the weight shift towards the trail leg (Welch, 1995). Foot down occurs when the lead foot makes complete contact with the ground ending the recoiling effect of foot off, and starting the transfer of energy from the now closed chain (Welch, 1995). Ball contact is the moment the bat strikes the ball (Welch, 1995). Another study divided the swing into: stance, stride, coiling, swing initiation, swing acceleration, and follow through (Fortenbaugh, 2011). For the sake of examining lower extremity strength asymmetries, this review will be utilizing the former sequence of foot off, foot down, and ball contact. In order to maximize rotational velocities of the bat, and thus exit velocity of the ball, hitters must efficiently utilize ground reaction forces generated from their own kinetic energy (Fortenbaugh, 2011). Momentum through all planes of movement is transferred from the musculoskeletal system into the ground and utilized back through the kinetic chain resulting in rapid rotational forces of the hitter's instrument; the bat. Each link in the kinetic chain distributes energy proximally to distally (Fortenbaugh, 2011). Similarly to the pitching delivery, sequential timing is an irreproducible phenomenon but is essential for maximal performance outcomes for the hitter (Welch, 1995). This cascade of timing begins with the initiation of foot off.

Foot off begins when the lead foot leaves the ground and the hips along with the shoulders shift toward the trail leg (Welch, 1995). The trail leg forces then increase to 102% of the hitter's bodyweight, suggesting a need for appropriate distribution of maximal overload forces (Welch, 1995). After the arms and shoulders counter rotate, the stride continues in anticipation for the lead foot going into the foot down phase (Welch, 1995). A previous study showed that before foot off occurs, hitters will have significantly more weight displacement in their lead leg than their trail leg (Fortenbaugh, 2011).

When the lead heel strikes the ground, foot down phase is initiated and immediately weight is translated forward with a total force equal to 123% of body weight (Welch, 1995). This is confirmed by another, more recent study showing the similar distribution of horizontal body weight force (123%) to the lead leg after weight is shifted forward (Fortenbaugh, 2011). At one point during the swing, the lead leg presented over 200% of force in comparison to body weight (Fortenbaugh, 2011). At the apex of the swing, the lead leg goes into triple extension, propelling the lead hip backwards. Simultaneously the trail leg drives the trail hip forward, resulting in a forceful counterclockwise rotation of the hips, transferring all stored potential energy into the hitter's bat, and eventually the ball (Welch, 1995).

Purpose

The purpose of this study is to examine the presence of lower extremity symmetry and how it affects bat handle velocity and pitching exit velocity of college baseball players. Both strength and conditioning professionals and baseball coaches are in a constant pursuit of optimizing on-field performance and lower extremity symmetry could be a significant determinant of such. Since previous research is inconclusive on whether or not the BLD or the LSI are beneficial or detrimental to performance, further research is warranted. Since there are both rapid propulsive and rapid deceleration forces in hitting and pitching, it is hypothesized that a decreased prevalence of the BLD and LSI would be correlated with increased pitching velocity and bat handle velocity.

Methods

In order to determine whether lower extremity asymmetry affects sport performance, previous studies have utilized force plates and isometric contraction exercises. Since the sport of baseball involves significant explosive and maximal strength ability in order to perform at high levels, the force-time producing characteristics displayed during an isometric mid-thigh pull was deemed the most appropriate test to measure. Previous research has shown the biomechanical requirements of the pitching delivery and batting swing, but further research is necessary to determine the force producing requirements of both the trail and lead legs. With on-field performance metrics readily available, the purpose of this study is to examine the relationship between lower extremity kinetic asymmetry and on-field force production capabilities.

Participants

Twenty-five collegiate baseball players (age = 20.25 ± 2.2 years; mass = 80.44 ± 8.15kg; height = 1.75 ± .09 m) volunteered to take part in this study. Inclusion criteria included a minimum of two years of resistance training experience, with any participants with any lower or upper extremity injuries during the time of testing being excluded from participation. Written consent forms were read, signed, and returned in order to be eligible for participation. Ethical approval will be granted from the Institutional Review Board.

Research Design

This study aims to accumulate and compare quantitative data regarding the bilateral deficit and the lower extremity asymmetry index by implementing three separate tests along with on-field data collection: (1) the bilateral isometric mid-thigh pull, (2) a left and right unilateral isometric mid-thigh pull, and (3) bat handle velocity and pitching velocity. The summation of the lead and trail unilateral isometric mid-thigh pull will be compared to the bilateral isometric mid-thigh pull in order to determine the severity of the bilateral deficit in each participant. The bilateral isometric mid-thigh pull will be performed to assess the LSI during maximal force production. The severity of the bilateral deficit will be compared to the LSI in order to determine their relationship in this population. The bat handle and pitching velocities will be compared to both the levels of the BLD and the LSI in order to determine how differences in lower extremity force production can potentially affect on-field performance metrics.

Instrumentation

Bilateral and unilateral isometric mid-thigh pulls will be collected on two Hawkin Dynamics Force (Hawkin Dynamics, Westbrooke, ME) plates with an operating frequency of

1000 Hz. Bat handle velocity will be collected with a Blast Motion (BLAST, Carlsbad, CA) hitting device while pitching velocity will be collected with a Rapsodo Baseball (Rapsodo, Chesterfield, MO) pitching monitor.

Procedure

Participants will be required to perform a standardized warm-up including a cardiovascular warm-up to increase intramuscular temperature, a dynamic warm-up to activate and mobilize skeletal tissues, and plyometric jumps to utilize central nervous potentiation. Following the standardized warm-up and establishing a knee angle of 135-145 degrees of knee flexion, participants will be instructed to perform two warm up repetitions of the bilateral isometric mid-thigh pull at "50% and 75% effort" spaced one minute apart to allow for rest. After the 75% effort pull has been performed and the participant has been strapped to the bar with weightlifting straps, following a "3, 2, 1 pull" countdown, participants will be instructed to "pull as fast and as hard as possible". Participants will be allowed two trials at maximal effort with one minute between trials. Following the bilateral trial, participants will be instructed to replicate the isometric mid-thigh pull with their left and right legs. Trials will be performed on the left leg, followed by a 1-minute rest, then the right leg until two trials are completed for both legs.

Participants are ineligible for participation if they are experiencing any soft tissue injury during time of testing. Participants will be required to perform the standardized warm-up which minimizes risk of injury during testing. One or more certified strength and conditioning specialists (CSCS) will be present to administer testing while observing at all times. Voluntary consent forms are to be completed and signed by all participants.

Statistical Procedure

The presence of the BLD was calculated by utilizing Howard and Enoka's (1991) formula: BI (%) = (100 x bilateral / (right unilateral + left unilateral) – 100)[2]. The bilateral index determined the presence of bilateral facilitation (>1) or bilateral deficit (<1). And LSI was determined by the formula: ((left value – right value)/(sum of values)*100) where values greater than zero indicated a left side asymmetry, values less than zero indicated a right side asymmetry (C. Bailey, 2018). In this study, in order to establish directionality of asymmetry, values below zero indicated an asymmetry towards the trail leg and values above zero indicated an asymmetry toward the lead leg. Pearson's Correlations Coefficient tests were run on statistical analysis software, JASP (Version 0.12.2; JASP Team, 2020), on five variables within the whole correlation and six variables within the pitchers and hitters groups to analyze both group correlations and hitters and pitchers separately. Trail_U_IMTP_Average and Lead_U_IMTP_Average were the average forces in newtons produced by the athlete's trail leg and lead leg respectively, after two trials of the unilateral isometric mid-thigh pull. SUM was the summation of the Trail_U_IMTP_Average and Lead_U_IMTP_Average. AVERAGE_BI_IMTP was the average bilateral isometric mid-thigh pull after two trials. ABS_LSI_(%) came from taking the absolute value of the LSI, in order to determine directionality of the asymmetry.

Results

Whole Group Correlation Matrix
Pearson's Correlations
n=24

	Lead_U_IMTP_Average	Trail_U_IMTP_Average	SUM	AVERAGE_BI_IMTP	BI (%)
1. Trail_U_IMTP_Average	0.88				
	< .001				
2. SUM	0.97	0.96			
	< .001	< .001			
3. AVERAGE_BI_IMTP	0.82	0.81	0.84		
	< .001	< .001	< .001		
4. BI (%)	-0.11	-0.09	-0.10	0.44	
	0.599	0.676	0.631	0.031	
5. ABS_LSI_(%)	-0.14	-0.08	-0.12	0.03	0.28
	0.514	0.711	0.577	0.898	0.179

After running correlation statistics through JASP, it was found that when comparing both hitters and pitchers together, Lead_U_IMTP_Average, Tail_U_IMTP_Average, AVERAGE_BI_IMTP, SUM had correlations ranging between r = 0.81 and r = 0.97 (p<.001). Also, Pearson's Correlation Coefficient found nearly no correlation between AVERAGE_BI_IMTP and ABS_LSI_(%) (r = 0.03, p = 0.898).

When running Pearson's Correlation Coefficient with the hitter's data, multiple variables were found to have strong to very strong correlations including: Trail_U_IMTP_Average, SUM, AVERAGE_BI_IMTP, Average_Batt_Handle_Velocity, and ABS_LSI_(%) (r = 0.62-0.902, p = 0.032-<0.001). There was nearly no correlation between BI (%) and ABS_LSI_(%) (r=0.02, p =

0.951). There was moderate correlation between BI (%), ABS_LSI_(%), Trail_U_IMTP_Average, SUM, and AVERAGE_BI_IMTP (r = 0.447-0.646, p = 0.145-0.023).

Hitter's Correlation Matrix

Pearson's Correlations

n=12

	Lead_U_IMTP_Average	Trail_U_IMTP_Average	SUM	AVERAGE_BI_IMTP	BI (%)	ABS_LSI_(%)
1. Trail_U_IMTP_Average	**0.91**					
	< .001					
2. SUM	**0.979**	**0.969**				
	< .001	< .001				
3. AVERAGE_BI_IMTP	**0.882**	**0.857**	**0.902**			
	< .001	< .001	< .001			
4. BI (%)	**0.073**	**0.053**	**0.098**	**0.511**		
	0.821	0.869	0.763	0.09		
5. ABS_LSI_(%)	**0.646**	**0.447**	**0.527**	**0.518**	**0.02**	
	0.023	0.145	0.078	0.084	0.951	
6. Average_Batt_Handle_Velocity	**0.783**	**0.778**	**0.77**	**0.733**	**0.121**	**0.62**
	0.003	0.003	0.003	0.007	0.708	0.032

When running Pearson's Correlation Coefficient with the pitcher's data, multiple variables were found to have strong to very strong correlations including: Trail_U_IMTP_Average, SUM, and AVERAGE_BI_IMTP (r = 0.859-0.962, p = <0.001-0.003). Unlike the hitter's correlation statistics, the pitcher's correlation matrix displayed negative weak and moderate correlations between variables including: BI (%), ABS_LSI_(%), Lead_U_IMTP_Average, Trail_U_IMTP_Average, SUM, and AVERAGE_BI_IMTP (r = -0.188 - -0.504, p = 0.094-0.558). The pitcher's data also displayed moderate correlations between variables including: AVERAGE_BI_IMTP, BI (%), and Average_Pitching_Velocity (r = 0.403-0.534, p = 0.073-0.194).

Pitcher Correlation Matrix
Pearson's Correlations
n=12

	Lead_U_IMTP_Average	Trail_U_IMTP_Average	SUM	AVERAGE_BI_IMTP	BI (%)	ABS_LSI_(%)
1. Trail_U_IMTP_Average	0.859					
	< .001					
2. SUM	0.961	0.962				
	< .001	< .001				
3. AVERAGE_BI_IMTP	0.784	0.77	0.798			
	0.003	0.003	0.002			
4. BI (%)	-0.217	-0.188	-0.219	0.403		
	0.498	0.558	0.495	0.194		
5. ABS_LSI_(%)	-0.504	-0.398	-0.448	-0.236	0.391	
	0.094	0.199	0.144	0.46	0.208	
6. Average_Pitching_Velocity	0.211	0.313	0.24	0.534	0.491	0.211
	0.51	0.321	0.453	0.073	0.105	0.51

Discussion

When assessing the relationship of lower extremity asymmetry to on-field baseball performance, it is important to readdress the potential reasons behind the BLD and LSI. Within this study, in both the pitching and hitting groups, the athletes with the lowest SUM presented the most extreme BLD deviance (SUM = 4763N, 5079N, BI (%) = -31.87%, -47.88%). The pitcher with the lowest SUM presented the highest LSI (20.18%) towards the trial leg. Another subject presented higher force production during their unilateral isometric mid-thigh pull than their bilateral test (Trail_U_IMTP = 3263N, AVERAGE_BI_IMTP = 3161N). This presents an entirely new question as to why this athlete was able to express more force unilaterally than bilaterally. It is also worth noting that within both the pitching and hitting groups that there were moderate to moderately strong correlations (0.733 & 0.534) between velocity metrics and AVERAGE_BI_IMTP, suggesting that higher force producing qualities likely transition into on-field performance. Asymmetries could result from muscular strength, neurological factors, and even compensatory neural patterns developed during task-specific outcomes (Wang, 2019). Given that both hitting and pitching movements are movements where force is translated in a unilateral environment, it would be beneficial to understand the discrepancies in force producing capabilities of limbs separately. Muscle force production capabilities are traditionally greater in the dominant limb than the non-dominant side, along with greater stability than the non-dominant side. (Wang, 2019). Other possibilities as to why extremity asymmetries are present suggest cerebral dominance in the brain in order to reinforce dominant movement patterns (Kaçoglu, 2019). While the understanding of asymmetries may not be clear, this study investigated if asymmetries could be beneficial or detrimental to on-field baseball performance metrics.

Regarding the entire group, the most notable statistics we found presented that unsurprisingly, a higher total strength (AVERAGE_BI_IMTP) was highly correlated with the summation of unilateral forces (SUM) ($r = 0.84$, $p < 0.001$). Within the entire group, not one subject presented bilateral facilitation. The most confident correlation was between LSI and AVERAGE_BI_IMTP ($r = 0.03$, $p = 0.898$), suggesting that lower extremity symmetry and maximal strength in this population had almost no correlation.

When analyzing the hitters group, five of six variables presented moderately strong correlations with Average_Batt_Handle_Velocity. Lead leg strength ($r = 0.783$, $p = 0.003$), trail leg strength (r = 0.783, p = 0.003), summation of unilateral strengths (r = 0.77, p = 0.003), bilateral strength (r = 0.733, p = 0.003), and severity of asymmetry (r = 0.62, p = 0.032) all demonstrated moderately strong correlations with Average_Batt_Handle_Velocity. High levels of maximal force production, and higher levels of separately unilateral force production are likely to be correlated with higher batt handle velocities due to the transfer of energy through the kinetic chain all the way to the batt. The only variable that was weakly correlated with bat handle velocity was BI (%) (r = 0.121, p = 0.708). Suggesting that bilateral deficit and facilitation have little relationship with performance outcomes within this population.

After correlating statistics were run within the pitchers group, only two performance variables showed moderate correlation with average ball velocity. AVEREAGE_BI_IMTP (r = 0.534, p = 0.073) and BI (%) (r = 0.491, p = 0.105) were the variables with the highest correlation to on-field performance metrics for pitchers. With a movement with as many minutiae as pitching, maximal strength may not be as necessary to produce maximal velocities. Motor synchronization as opposed to maximal strength may be advantageous in on field-performance metrics for pitchers. With a moderate correlation, there is still room to believe that maximal strength is a significant contributing factor, but not a requirement for high ball velocities. Other noteworthy correlations were between severity of lower extremity strength and lead leg strength (r = -0.504, p = 0.094), trail leg strength (r = -0.398, p = -0.448), and summation of unilateral forces (r = -0.448, p = 0.144) all showed moderately negative correlations with average pitching velocity. This correlation shows that high unilateral force production may not be necessary for higher pitching velocities.

Within the whole group, this study suggests that lower extremity symmetry is likely not correlated with maximal strength. There is some evidence to suggest that maximal force production in hitters would likely be advantageous when attempting to generate higher bat handle velocities, thus higher ball exit velocities. On the same note, higher bat handle velocities displayed moderately strong correlations with the presence of unilateral strength asymmetries. On the other hand, pitchers benefited less from less maximal force producing capabilities during a maximal voluntary contraction. This could be due to the mere weight of a bat (~30oz) in comparison to a baseball (~5.5oz). Strength and conditioning professionals can use this information to create both a bilaterally and unilaterally challenging training environment for both hitters and pitchers. There is much more to understand about how lower extremity strength asymmetries affect performance. Further studies should look to examine force producing capabilities during both the hitting and pitching motions.

Limitations

There are relatively infinite factors determining on-field performance metrics like bat handle velocity and pitching ball velocity and this study does not aim to find the exact formula to maximize these metrics. This study is merely attempting to evaluate the correlation between limb asymmetry and athletic performance. One limitation was that the subjects are not professional athletes, so considerable heterogeneity may exist regarding strength and asymmetry levels. Also, this was their first time performing a unilateral isometric mid-thigh pull, so they were potentially not able to fully express their unilateral strength in the same way as they previously had in the bilateral test that they were more familiar with. Another limitation was that bilateral and unilateral strength were not categorized in comparison to the participants bodyweight.

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