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The Relationship of Strength, Mobility, and Performance Variables on Throwing Speed in Baseball Catchers

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THE RELATIONSHIP OF STRENGTH, MOBILITY, AND PERFORMANCE VARIABLES ON THROWING SPEED IN BASEBALL CATCHERS

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ABSTRACT

THE RELATIONSHIP OF STRENGTH, MOBILITY, AND PERFORMANCE VARIABLES ON THROWING SPEED IN BASEBALL CATCHERS

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Baseball is a popular sport worldwide and has thus garnered significant research focus, predominately of pitchers and hitters. However, research involving catchers is scant despite their major influence and consistent presence throughout a game. Therefore, the purpose of this study was to determine the relationship of lower body strength and mobility and performance with throwing speed in baseball catchers. We hypothesized that strength and mobility would have a positive relationship with ball speed, peak power generated while rising out of the squat position would be positively related to ball speed, shorter ascent time would be inversely related to ball speed, and catch to throw time would be inversely related to peak power.

Six baseball catchers of different skill and training levels varying between high school, college club, and college varsity participated in this study. Subjects' mobility and isokinetic peak torque at 60 deg/s and 180 deg/s at the hip, knee, and ankle were tested. Motion capture recorded subjects throwing mechanics while they were tossed five balls and instructed to catch, pop up, and throw into a net in front of them. The relationships of range of motion and peak torque with ball speed were assessed using correlations. Linear regressions were used to determine the relationship of peak power, ascent time, and catch to throw time each with ball speed. Results showed that there were significant relationships between peak power and ball speed and ascent time and ball speed. Although not significant due to our small sample size, medium to large coefficients were found for hip range of motion and ball speed, ankle plantar flexors peak torque

at 180 deg/s, and knee extensors peak torque at 180 deg/s, each with ball speed. Findings from this study can provide important insights about the flow of power in catchers and how greater strength in the lower extremity may play a role in greater power and faster ball speeds. The findings are beneficial for player training and development in that catchers may be able to decrease their pop time without having to sacrifice accuracy or speed to optimize their level of performance.

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Chapter 1: Introduction

Background

Baseball is becoming more competitive as technology advances for training and development use. However, most research delves only into the mechanics of pitching and batting, often overlooking the other positions (Fleisig et al. 2011; Ozkaya et al. 2018). Most research studies also only examine the upper extremities. In contrast to pitching, few studies focus on catchers and even fewer target lower extremity mechanics (Dooley et al. 2019; Gray et al. 2015; Peng et al. 2015). Considering their role in baseball, lower extremity mechanics are an important consideration for catchers.

Baseball catchers' role on the field requires a lot of repetitive motions, the main one being squatting. Each catcher performs about 146 squats per nine-inning game (Dooley et al. 2019). Throwing is also an important factor in a catcher's performance. A catcher must make a quick throw to the base in an attempt to get a runner out after standing up out of their squat stance. This full movement from stance through the throw is referred to as "pop time" (Major League Baseball, n.d.). Pop time is a key assessment of a catcher's performance (Major League Baseball, n.d.).

Although not in catchers, research has illustrated large loads placed on the lower extremities during deep squats (Escamilla et al. 2001, Cotter et al. 2014, Demers et al. 2018). A similar squat is observed in a catcher's stance, although they are typically unloaded and maintain this position for prolonged periods. As such, it can be easily assumed the repetitive deep squat motion places a lot of pressure on catchers' hips, knees, and ankles.

Previous studies examining catchers have found that with prolonged knee flexion, players often experience increased discomfort and pain (Gray et al. 2015). Although there has not been a lot of research on what exactly causes this pain and discomfort in the knee joint, research has suggested increased moments in the knee joint during the catcher's stance (Dooley et al. 2019) are a primary mechanism. Dooley et al. 2019 also found that knee moments were decreased when subjects sat higher in their squat (90 degrees knee flexion). The findings show that even incremental reductions in knee flexion angle in a deep squat position can significantly reduce the moment that is causing pain and discomfort (Dooley et al. 2019), which may allow for reduced pop times.

An opposing view to this can be observed in a study that found that the deep squat provides an effective training method for protection against injuries (Hartmann et al., 2013). Deep squat training does this by strengthening the lower extremity throughout the full joint range of motion in contrast to partial squat depths (Hartmann et al., 2013). Squat width during a catcher's stance also plays an important role during game play in relation to throwing, pop time, and movement. With regards to mobility, the wide catcher stance (wider than shoulder width) has been associated with increased hip flexion and ankle dorsiflexion in catchers but decreased knee flexion angles (Demers et al. 2018). Increased mobility during a catcher's stance has been shown to allow them to sit comfortably in their stance and give them the ability to move their body freely to catch the ball (Li et al. 2015; Cressey 2013).

Overall, full body training is important for maintenance and/or improvement in a catcher's performance. However, little research has focused on catchers and their lower extremities. Although it is assumed that strength and mobility during a deep squat can translate to game play, research examining catchers' strength and mobility along with lower extremity biomechanics during their normal duties (in deep squat, standing up, and throwing) is warranted to support or refute these assumptions.

Purpose

Despite the wealth of knowledge regarding baseball pitchers, little research has been conducted on baseball catchers. The limited research that has been conducted generally focuses on strength, stance/loading at the knee joints, or throwing mechanics individually. However, these two aspects of a catcher's mechanics are rarely, if ever, individual tasks. Therefore, it is pertinent to assess how measures such as strength, mobility, and power are related to throwing mechanics. Specifically, this study aims to determine the relationship of lower body strength, mobility, time to ascent (from full squat depth), peak power generated during the ascent, and catch to throw time with throwing speed in baseball catchers.

Hypotheses

This study hypothesized that greater strength and mobility at the hip, knee, and ankle would result in faster ball speeds from catchers. Specifically, we hypothesized

1. Strength and mobility at the hip, knee, and ankle would have a positive relationship with ball speed.
2. Peak power generated while rising out of the squat position would be positively related to ball speed.
3. Shorter ascent time would be inversely related to ball speed.
4. Catch to throw time produced by catchers would have a significant inverse relationship to peak power.

Significance of this study

This study is important to understand the relationship between the strength and mobility of the lower extremities and throwing speed in baseball catchers. Based on this knowledge, it may show that catchers with more mobility and strength can decrease pop time and increase throwing speed. Findings from this study will be beneficial for player development to increase overall performance.

Chapter 2: Review of Literature

Introduction

This literature review will examine 1) the deep squat, transfer, and throw of baseball catchers and how a catcher's mechanics are affected by different stances, 2) how the mechanics of the deep squat and varying stances relate to throwing, and 3) how mobility and strength affect overall performance during games and injury prevention and maintenance.

Mechanics of baseball catchers

Job of the catcher

The catcher is one of the most important positions in baseball. It is the catcher's job to control what is happening on the field. The catcher stands behind home plate and is responsible for receiving pitches from the pitcher and throwing to a base (first, second, and third base) to get runners out. Prior to a pitch being thrown, the catcher is in a relaxed squat stance ready to give the signal to the pitcher to call the pitch. This is referred to as the signal stance, or primary stance. After the pitch is called, the catcher will move into their receiving stance, or secondary stance. The catcher will comfortably squat with feet approximately shoulder width apart with the glove arm extended out in front. This stance can vary if there are any runners on base. When this occurs, the catcher will shift their weight to a position that they are ready to throw in.

The deep squat and catcher stance

Near maximal angles of sagittal knee flexion (~ 124°) are observed during a deep squat (Endo et al. 2020). Baseball catchers perform deep squats about 146 times per nine-inning game (Dooley et al. 2019) and hold this position for multiple seconds. This prolonged movement places more than normal forces (> 25 Mpa) on the muscles surrounding the knee joint (Dooley et al. 2019). Support for deeper squats mentioned in a study by Dooley et al. 2019, is that catchers may be squatting deeper to relieve stress on their knees. Catchers in a deeper squat have shown an increase in thigh contact forces that removes some of the load off the knee (Dooley et al. 2019).

The increase of thigh-contact force has been validated in other studies where it was observed that higher thigh-contact force decreases load on the knee joint (Zelle et al. 2007). Dooley et al. 2019 also found that the maximum load on the knee joint is occurring at the instance that catchers begin to come up out of the squat from the starting position of the knee in their secondary stance.

Catchers often complain about discomfort and pain in their knee joints that is attributed to prolonged deep squatting (Gray et al., 2015). A study by Gray et al., 2015, aimed to mitigate knee pain during deep squats by using knee savers. Knees savers are a piece of foam that attaches to the back of the players calves so that when in a deep squat position, the foam would allow the player to "sit" and relieve stress on the joints/muscles. Although counterintuitive, researchers found that there were no significant decreases in knee flexion angles while using knee savers (Gray et al. 2015). It was also observed that players with shallow squat depth flexed more at the knee with knee savers and those with deeper squat depth flexed less at the knee with knee savers.

Research has also examined the influence of stance width on depth/knee flexion. A study by Peng et al., 2014 examined two different stance positions: a general stance and a wide stance. The study found that knee joint flexion in general stance was significantly greater as compared to wide stance (Peng et al. 2014). Regardless of the stance used by catchers, power generated from the lower extremities of catchers was greater when weight-shift throwing was used (Peng et al. 2014). Peng et al. 2014 also found that this movement resulted in faster ball speeds from catchers.

Studies examining weighted back squats have also focused on stance width (Escamilla et al. 2001). Researchers observed weighted squatting at a preferred narrow stance width (24cm - 31cm) and a preferred wide stance width (53cm - 65cm). Here, a narrow stance was defined at

75% shoulder width, and a wide stance was defined as 140% shoulder width (Escamilla et al. 2001). This stance width is similar to what a wide or narrow stance width would look like in catchers. It was found that the narrow squat stance resulted in greater gastrocnemius involvement, while the wide squat stance resulted in greater hamstring involvement. All the stances involved equal quadricep activations (i.e., no significant differences were observed). When observing forces acting on the knee, the wide stance was more effective in minimizing tibiofemoral shear forces (Escamilla et al. 2001).

Baseball catchers assume a similar stance width to those seen in weighted back squats when receiving the ball. For a normal stance, catchers stand with feet apart at an approximate shoulder-width while a wide-stance is considered any stance where feet are wider than shoulder-width (Peng et al. 2015). With information from these studies, it could be concluded that for catchers to have less force acting on the knee joint and less pain and discomfort, they could try a different stance such as wide squatting.

Throwing

Throwing is also an important part of the catcher's game. When pitchers are in a game, they have time to think about their pitch before they throw it. In contrast, catchers must react to the pitcher/pitch and in a very short time. When a pitch is thrown and a runner leaves the base, catchers come up out of their deep squat stance phase to quickly throw the ball to base to get an opposing player out. The timing of this is an important assessment of performance measured by coaches. In the MLB, the average pop time for catchers is 2.01 seconds (Major League Baseball, n.d.). Catchers must make a decision in the game on how to decrease their pop time to be most efficient when making a throw to get a base runner out. This usually ends in catchers having to sacrifice power when coming up out of their stance, ball velocity, or throwing accuracy to the base. A study by Fortenbaugh et al., 2010, observed the different mechanics of catchers throwing motions when compared to other position players and found that catchers are vastly different in multiple different kinematic variables (Fortenbaugh et al. 2010). The most notable differences observed are a shorter stride, reduction in pelvis-trunk separation angle, less forward trunk tilt, and excessive elbow flexion that led to a reduction in ball velocity in catchers when compared to pitchers (Fortenbaugh et al. 2010).

Placement of the feet during catching has also been shown to cause a significant reduction in ball velocity (Fortenbaugh et al. 2010). Specifically, catchers have a more open foot position and a closed foot angle when compared to pitchers (Fortenbaugh et al. 2010). Catchers must assume this position due to not having the same amount of time that a pitcher does to throw and must sacrifice ball velocity to make quicker movements to decrease pop time. The reduction in ball velocity is due to the positioning and quick movements that catchers must make from catching an unpredictable ball to coming up out of their stance phase. This makes their transfer and throw less powerful and quick.

Because of the reduced trunk and shoulder rotation velocities, catchers need to minimize their time elsewhere to stay under the critical 2.01 sec. pop time threshold. Greater lower extremity strength could allow the catcher to generate more force and a more powerful explosion out of full squat depth, shaving critical milliseconds off their rise time. The generated power can also potentially be transferred through the arm and to the ball, ultimately enhancing a catcher's throw.

Another way catchers try to be quick about the timing of their throws is by throwing from their knees when possible. Throwing from the knees eliminates the extra work of standing all the way up but does not allow catchers to gain as much torque for the throw because it reduces the catcher's ability to utilize their kinetic chain (Plummer et al., 2013). It was found in a different study that a way to decrease pop time by catchers is to utilize the quick throw (Kawabata et al., 2020). The quick throw emphasizes shortening the time from ball catch to lead foot contact with the ground while still producing enough power for increased ball velocity (Kawabata et al. 2020). Utilizing throwing techniques such as the quick throw while generating power from the lower extremity will help catchers to decrease their pop times without having to make sacrifices for ball velocity.

Mobility and Strength

There are many different opinions about how to optimize mobility and strength for performance. It is a common belief that being stronger and more flexible will help all athletes. Catching is a position in baseball that requires prolonged periods of athletes sitting in a deep squat during their catcher stance, as mentioned before. This puts extra force on the hip, knee, and ankle joints causing more injuries in these players (Kilcoyne et al. 2015). It is assumed that increasing strength and mobility of these joints would help improve this by allowing the catcher to sit comfortably in their stances. For a catcher, sitting comfortably in their stance is squatting with the back straight where the back and shoulders are directly over the feet so that the catcher is balanced (Barksdale 2011). Having more mobility in these joints also allows catchers to have more sway to get their body in front of the ball when preparing to receive a pitch to decrease their pop time (Barksdale 2011). The ACSM recommends that when athletes perform resistance training, they should be working through their full range of motion. Training through the full range of motion allows strength adaptations to occur at all joint angles while also increasing flexibility (Cotter et al. 2014). Training to increase range of motion and flexibility has been shown to improve strength and performance and decrease overall risk of injury (ACSM 2018). Cotter et al. 2014 recommends that deep squat training be implemented into training programs and rehabilitation for athletes, especially ones that will perform repetitive squat movements, such as baseball catchers. Cotter et al. 2014 also observed how different loads affect the patellofemoral joint reaction force on the knee joint. The authors found that when increasing from 50% 1RM load to 85% 1RM load, the force in the knee joint increases (Cotter et al. 2014). The results from Cotter et al. 2014 are to be expected, but it provides further knowledge about how increasing loads affect forces in the knee joint which can be helpful for training purposes.

A key factor in a catcher's training is to focus on power in their lower extremities. Possessing greater power gives catchers the ability to stand up out of their stance faster after catching the ball to decrease pop time. Training programs that focus on generating power from the lower extremities can be useful in catchers, such as jump squat training. A way to assess similar power in a catcher's movement is to observe step time in lead-step throwing (Kawabata et al. 2020). Step time is defined as the point when the ball is caught by the catcher to the instance that the lead foot makes contact with the ground (Kawabata et al. 2020). Lead-step throwing is the same as hop throwing, which is defined as the throwing motion in stepping forward with the stepping foot after stepping forward with the pivoting foot (Kawabata et al. 2020). This study found that implementing a squat jump training program can increase lower extremity power leading to decreases in step time (Kawabata et al. 2020). This could be an important training method for catchers trying to improve explosiveness and footwork throughout their transfer.

Another important aspect of performance for catchers is range of motion/mobility at the hip, knee, and ankle joints. Many catchers suffer from injuries due to limited range of motion in the hip, knee, and ankle (Li et al. 2015). Dysfunctional hip range of motion can alter lower extremity kinematics and predispose athletes to hip and groin injuries (Li et al., 2015). Li et al. 2015 found that there is a correlation between decreased hip range of motion, specifically internal rotation, and hamstring and groin injuries. Ankle mobility can also have a large effect on a catcher’s ability to move to catch the ball. With increased dorsiflexion during squatting, the catcher can sit lower in their stance (Cressey 2013). This allows them to easily sway to move quicker to get their body in front of the ball to catch it. Knee mobility is also an important factor in a catcher's stance. Having full range of motion at the knee will help catchers sit comfortably in their stances. Increased mobility in these joints will be beneficial to improving strength and performance. Increased strength and performance will allow catchers to catch/throw more effectively. Looking at variables such as mobility throughout a season could help coaches to catch injuries before they happen.

Conclusion

Mobility and strength of the hip, knee, and ankle are important when observing catcher mechanics. It is possible increased mobility and strength can minimize joint pain and improve performance. By focusing on joint mobility and strength training to allow muscle adaptations to occur, players will be able to minimize pain in their joints. The throwing motion also plays a role in this since it is one of the most important factors of a catcher’s game. Catchers need to be able to come up out of a deep squat stance quickly and to transfer power/energy from their lower extremities throughout their torso/arms to be able to release the ball quickly at a high velocity. Thus, research should examine the relationship between a catchers’ performance (i.e., pop time, throwing speed) and lower extremity strength and mobility to ensure that players are optimized for their performance and reducing injury risk.

Chapter 3: Methodology

Subjects

Six healthy baseball catchers aged 16-30 years with at least one season of experience as a catcher at the high-school level were included as subjects for the study (Table 1.). Subjects must have had no lower/upper extremity surgery in the past 12 months and no recent injuries to the upper or lower extremities in the past 3 months that caused them to not have the ability to play in a game. Only males will be included in the study because baseball is a male only sport at the upper level.

Experimental Design

Protocol

Data collections consisted of strength and mobility measurements as well as motion capture. Data collections were performed in the Neuromechanics Laboratory, room 1007 of the Student Recreation Center (SRC). Prior to collections, each subject was asked to not partake in any strength training within 24 hours of testing to minimize any detrimental effects it may have on range of motion and strength.

Mobility and Strength

Subjects were first informed of the entire research procedures and asked to fill out the informed consent form, followed by completing the medical history/playing history questionnaire. Next, subjects were asked to perform strength and mobility testing of the hip, knee, and ankle using a HUMAC NORM dynamometer.

Mobility testing were performed according to manufacturer guidelines (https://humacnorm.com/humac-norm/). Active hip, knee, and ankle range of motion in the sagittal plane define the "mobility" of the respective joints. Subjects were asked to actively move each joint as far as possible in each direction (flexion/extension). Following mobility testing, strength testing was conducted. Each subject performed 2 sets of 3 repetitions with 2 minutes rests in between two isokinetic tests moving at 60 degrees per second and 180 degrees per second. For continuity with the current literature, two sets of an isometric strength test were also performed at the hip, knee, and ankle. The isometric strength tests were performed at predetermined joint angles of 45 degrees hip flexion for the hip with the knee flexed, 80 degrees knee extension for the knee while seated (hip ~ 90 degrees), and 15 degrees dorsiflexion for the ankle while laying prone (knee is neutral) (Barbero et al. 2016; Kim et al. 2015; Li et al. 2015).

Motion Capture:

The next step of the data collection covers performance of catcher responsibilities. Subjects were asked to wear spandex shorts, be shirtless, and wear their own cleats.

Kinematic data were collected using a 10-camera three-dimensional motion capture system (400 Hz, Vicon Vantage). Forty-four reflective markers were attached to body landmarks on the throwing arm, torso, pelvis, and bilaterally on the lower extremities, in agreement with recommendations by the International Society of Biomechanics recommendation for reporting human joint motion (Wu, et al., 2002; 2005). Specifically, markers were placed unilaterally on the 2nd and 5th metacarpal heads, hand, medial and lateral styloid processes, medial and lateral humeral epicondyles, jugular notch, xiphoid process, medial border of the scapula, inferior angle of the scapula, C7, T8, T12, L3, L5, transverse processes of L4, and bilaterally to the acromion processes, PSIS, posterior lateral pelvis, iliac crest, ASIS, greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleoli, 1st and 5th metatarsal heads, and second distal toes. Along with individual markers, four markers attached to rigid plates were placed on the dominant forearm and upper arm and bilaterally on the thigh, shank, and heel. 14mm diameter markers were used for the full body, except for the hand and back that were 9mm markers.

Ground reaction force data were collected using four force platforms (2000 Hz, FP-4060, Bertec, Inc.) within a custom-built wooden platform and covered with carpet. If necessary, subject's stances were adjusted so that only one foot interacts with each force plate at a time.

An instrumented baseball (Diamond Kinetics, Inc.) was used to record ball speed (mph), rotations per minute, spin efficiency (%), and direction.

Following marker placement, subjects were asked to perform their normal warm up routine, for no more than 10 minutes, until they were ready to begin collections. Subjects were asked to assume a catching stance that they would use with runners on base (secondary stance) with a force plate under each foot. Subjects threw a total of 5 times from the catching platform into a net that was approximately 15 feet away. Following typical methods for assessing pop time in catchers, subjects were tossed a ball from approximately 15 feet away.

Data Processing

The average of the peak moment generated during each strength test/set was calculated and normalized to body weight (Nm/BW).

Three-dimensional kinematic data and ground reaction force data were imported into the Visual3D software. An 11-segment (each with 6-degrees of freedom) three-dimensional inverse dynamics model was then constructed from marker position data through each movement trial. The segments included the trunk, pelvis, right and left thigh, right and left shank, right and left foot, right upper arm, right forearm, and right hand. The shoulder joint was defined using markers placed on the acromions and a vertical offset of 0.17 times the distance between acromions. In preliminary testing, this offset was found to match predictions using functional shoulder joint predictions. The Davis method was used to determine hip joint centers. The center point of the femoral epicondyles and malleoli defined knee and ankle joint centers, respectively.

The center of mass (COM) was calculated using Visual3d's built-in function, which is based on the principle of center of gravity calculations. COM power will be calculated as the product of COM vertical velocity and net vertical forces (sum of GRF & bodyweight) from the start of the COM's upward motion to COM's peak height. Powers were normalized to body mass * leg length (obtained from inverse dynamics model). Ascent time (sec) was defined from the start of the COM's upward motion to COM's peak height. Catch-Throw time (sec) was defined from the start of the COM's upward motion to the instant of ball release.

Statistical Analysis

All descriptive data is presented as mean ± SD. The relationship among strength (dynamic) and mobility with position-specific performance variables (COM peak power; ascent time and catch-throw time) with ball speed were first visually assessed using scatter plots. Linear, logarithmic, power, or quadratic fits were implemented where appropriate. Relationships were considered weak, moderate, and strong relationships when the correlation coefficients (r) were < |0.30|, between |0.31| and |0.69|, and > |0.70|. The significance level was set a prior at $p<0.05$

Linear regression analyses were performed using built-in software functions (SPSS; Version 27.0; IBM SPSS Statistics for Windows, Armonk, NY, USA). Regression assumptions of linearity, homoscedasticity (scatterplot of residuals/expected values), outliers/influential data points (standardized DfBeta > 2/sqrt(n)), and distribution of the residuals (via Quantile-Quantile plots of residuals) were assessed, and any violations are reported. Analysis of variance (ANOVA) results for each regression are reported, including F-statistic, p-value, and R^2. When strong influential data points are found, ANOVA results are reported for the model with/without the influential data points.

Chapter 4: Results

Mobility and Strength

Mobility means and SD of degrees for the hip, knee, and ankle joints are presented in Table 2. Raw peak torque (Nm) means and SD for the hip, knee, and ankle flexors and extensors at 60 deg/s and 180 deg/s are presented in Table 3. Peak torque normalized to body weight are presented for the hip, knee, and ankle flexors and extensors at 60 deg/s and 180 deg/s are presented in Table 4.

Because of the limited number of subjects, the relationships of mobility and strength (n=30) with ball speed were only analyzed via linear correlations. There were no significant relationships found between hip ($r = 0.729$, $p = 0.100$), knee ($r = 0.084$, $p = 0.875$), or ankle ($r = -0.139$, $p = 0.793$) range of motion with ball speed (Table 5). There was no significant relationship between ball speed and peak knee extension torque at 60 deg/s ($r = 0.287$, $p = 0.581$) or at 180 deg/s ($r = 0.554$, $p = 0.254$). There was no significant relationship between ball speed and hip extensor torque at 60 deg/s ($r = 0.307$, $p = 0.554$), or at 180 deg/s ($r = 0.142$, $p = 0.789$). There was no significant relationship between ball speed and ankle plantar flexor torque at 60 deg/s ($r = 0.328$, $p = 0.525$), or at 180 deg/s ($r = 0.753$, $p = 0.084$) (Table 6).

Peak Power

Peak power regression analyses had a significant relationship with ball speed ($F = 4.682$, $p = 0.040$, $r^2 = 0.153$) (Figure 2). Linear regression analyses showed that peak power did not have a significant relationship with catch to throw time ($F = 0.027$, $p = 0.870$, $r^2 = 0.032$) (Figure 1).

Throwing Speed

There was no significant relationship between catch to throw time and ball speed ($F = 3.379$, $p = 0.077$, $r^2 = 0.108$) (Figure 3). There was no significant relationship between ascent time and ball speed ($F = 0.011$, $p = 0.916$, $r^2 = 0.000$) (Figure 4). However, when significant outliers (standardized DfBeta>0.50) were removed, a significant relationship between ascent time and ball speed ($F = 4.775$, $p = 0.038$, $r^2 = 0.160$) was found (Figure 5).

Chapter 5: Discussion

This study was conducted to determine the relationship between lower extremity strength and mobility with throwing speed in baseball catchers. To do this, subjects were asked to perform isokinetic strength tests at two different speeds to determine peak torque along with active range of sagittal plane motion at the hip, knee, and ankle. Subjects were then asked to catch a tossed ball while in their secondary catching stance and then rise and throw the ball into a net in front of them. We hypothesized that strength and mobility at the hip, knee, and ankle would have a positive relationship with ball speed, peak power generated while rising out of the squat position would be positively related to ball speed, shorter ascent time would be inversely related to ball speed, catch to throw time produced by catchers would have a significant inverse relationship to peak power. Some results of the study supported the hypotheses, although some relationships were weak due to limitations of the study.

Results showed that there were no significant relationships between strength and mobility with ball speed. Although the correlation showed that the relationship was not significant, possibly strong relationships existed between hip range of motion and ball speed ($r = 0.729$, $p = 0.100$), average isokinetic peak torque of the knee extensors at 180 deg/s and ball speed ($r = 0.472$, $p = 0.345$), and average isokinetic peak torque of the ankle plantar flexors at 180 deg/s ($r = 0.648$, $p = 0.164$). Statistical significance was not achieved, possibly due to our limited sample size. With a larger sample size, it is possible that the data would follow a similar trend and a significant correlation may be observed. The weak statistical outcomes observed in the study could also be due to the diversity of the subjects (high school to collegiate catchers).

Generating power from the lower extremities is important for catchers to decrease pop time by exploding/moving out of their stance quicker. During the study, we found that there is a significant negative power relationship between peak power and ball speed (Figure 2). Catchers that were generating less power out of their ascent were throwing faster than those with greater power. This supports the general knowledge that catchers are having to make sacrifices during their transfer (from squat/ball receipt to beginning the throw) to decrease pop time. Here, it can be observed that catchers are sacrificing power to have the opportunity to focus on increasing their throwing speeds. A different view of this can is observed in a study by Peng et al. 2014 where inferences are made that greater power from the lower extremities resulted in greater ball speeds by catchers during weight shift throwing. A possible explanation for their results involved the greater upward-forward ground reaction force from the pivot foot and greater hamstring activation during push-off (Peng et al. 2014). Peng et al. 2014 found this to be the driving force of power generated through the throwing arm. This is an important finding to discuss where the source of ball speed is coming from. The flow of power begins in the lower extremities to drive power through the arm to produce greater ball speeds (Peng et al. 2014). It is likely that the source of power that affects ball speed isn't being produced from the lower extremities when rising from the squat, but from pivot foot contact during a catchers throw. In the current study, this is an explanation for why the catcher's peak power had a negative relationship with ball speed. Due to the short ascent time that a catcher has, there is not enough time to produce large peak power. It can be assumed that if a catcher performs lower extremity strength and power training, they will be able to rise from their squat quicker, ultimately resulting in a decreased pop time.

During the current study, we found that peak power may influence other performance variables. It is assumed that similar results would be observed in catchers during a game. This study included a realistic setup like what could occur in game for catchers. Catchers were asked to sit in their primary stance and pop into their secondary stance where they received a tossed ball and transferred the ball from glove to hand prior to throwing. This method ensured that catch to throw time would be more generalizable to their natural gameplay. These findings are important for training purposes of catchers to reduce pop time. Ways catchers can decrease pop time include decreasing the time it takes to come out of their stance and increasing throwing speed. Observations of how greater power affects variables such as ball speed and catch to throw time shows that catchers should focus training explosive power from the lower extremity to help decrease pop time.

Other variables were also considered for their effect on throwing speed. When removing significant outliers, we found a significant negative linear relationship between ascent time and ball speed ($p = 0.038$) (Figure 5). Outliers for ball speeds were removed to decrease the variance in the data. Here we observed that catchers with shorter ascent times had faster ball speeds. We also found that there was no significant relationship between catch to throw time and ball speed. Although not significant in this study ($p = 0.077$), catch to throw time and ball speed could be meaningful with a larger sample size (Figure 3). Assumedly, a shorter catch to throw time during a catcher's transfer could result in faster ball speeds. A catcher should be able to move quicker through their transfer if there is more power produced from the lower extremities. This drive of power through the body can elicit a decrease in catch to throw time while increasing ball speeds to overall decrease pop time.

It is possible that the results of this study were influenced by the diversity of age and experience level of our subjects. Previous studies have found that kinetic and kinematic variables vary among pitchers at different levels of development (Fleisig et al. 1999). Fleisig et al. found that higher level (skill and age) pitchers were able to produce greater ball speed generated by greater arm torques during their throws (Fleisig et al. 1999), despite no differences in the kinematics. This was expected due to the body having more time to develop strength adaptations in the upper and lower extremities (Fleisig et al. 1999). In the current study, catchers that were at a higher level of training or were older may have been able to produce greater peak torque from the lower extremities and produce faster ball speeds. It is difficult to determine if this had any effect on the results of this study due to the limited sample size. Greater ball speeds would be expected at a higher level of competition where players have been trained accordingly. Future research should delve into how age training level would affect throwing speeds in catchers to determine if there is an effect.

Limitations

This study contained limitations given the difficulty in recruiting and experimental set up. As previously stated, there was a small sample size. Some difficulty was expected due to the small subject pool to recruit subjects from. First, there are a limited number of colleges in the area and each with an average of four catchers on their rosters. On average a team's roster will contain 2-3 catchers at the high school level, 3-4 catchers at the college level, and 2 in minor and major leagues. Catchers at the college level have a busy training schedule making it difficult to find a time for them to be available for data collection. Due to this, we expanded the target population for this study to include players at the high school and older adult league level. Although previous research has found that there are no significant differences in throwing mechanics of players of different age and training level, we found that our subjects had differences in throwing speeds. Future studies should focus on recruiting a larger sample size of players. In this larger sample size, there should also be a focus on recruiting players of similar age and skill to close any gaps in the data that may be due to this such as difference in throwing speeds.

With the knowledge of the limited number of catchers to recruit from, many steps were taken to secure subjects for the study. Coaches from colleges, high schools, adult leagues, and training centers in the area were contacted for catchers that were interested in participating. Flyers describing the study were given to these coaches and posted on campus. Catchers interested in participating were screened for inclusion/exclusion criteria to ensure that they were able to complete the data collection. An incentive was offered for a drawing for a $50 amazon gift card drawing for every five subjects that completed the study. Previous studies that collected motion capture, EMG, or force data did not have a large subject base, similar to this study (Table 7).

Our experimental set up was designed to be as like game play as we could manage in our lab space. We found that having the net hanging so close in front of catchers when they were throwing may have affected the speed they were throwing. Without having the visual of throwing 127 feet to second base, catchers throwing speeds may have been slower than what they would throw in an actual game. Ensuring experimental conditions are as realistic to game play as possible will allow players to be more comfortable catching and throwing. This could be done by creating a space in the lab space where the net is able to be further away from the catcher or conducting the study on the field where conditions are the same as game play.

Practical Applications

This study is important in understanding the relationship between strength, mobility, and performance variables and throwing speed in baseball catchers. Findings from this study can give insights on the movements of a catcher to help with player development. By breaking down the components that affect a catcher's pop time, findings in this study can be used to evaluate catchers to find where there are deficits in a catcher's transfer. Implementing training to be quicker during the ascent and catch to throw time can help catchers to decrease their pop time. Findings show that lower extremity strength training can be beneficial for catchers to decrease pop time and increase throwing speed. Increasing strength in the lower extremities can also be beneficial for catchers to increase the power they are producing to increase throwing speed. Coaches can implement this information into training to work on decreasing pop time. Future research can use this study as a baseline to continue to study the movement of catchers for performance measures and injury risk. Overall, this study provides important preliminary insights on how strength and mobility of the lower extremity may increase throwing speed and decrease pop time. These findings are beneficial for player development to increase performance.

Chapter 6: Conclusion

This study showed that shorter ascent time and smaller peak power generated by catchers had significant relationships to ball speed. Relationships between hip range of motion and ball speeds, peak torque in the quadriceps and ball speeds, and peak torque in the ankle plantar flexors and ball speeds did not reach statistical significance despite their seemingly large correlation coefficients. However, significance could likely be found if the sample size was larger and less diverse in age and playing level. Findings from this study may provide insights on the relationships about the flow of power in catchers and how greater strength in the lower extremity may play a role in greater power and faster ball speeds. Overall, greater strength in the lower extremity can help catchers to produce quicker movements during ascent which may lead to decreased pop times without having to sacrifice throwing accuracy or speed to optimize their level of performance.

TABLES

Table 1. Subject Demographics

Subject	Height (m)	Weight (kg)	Age	Level of Play
1	1.79	81.02	19	College Varsity
2	1.79	77.22	21	College Club
3	1.68	73.5	28	College Varsity
4	1.88	80	17	High School
5	1.83	67.27	24	High School
6	1.73	78.18	23	High School

Table 2. Average range of motion of the hip, knee, and ankle (degrees) presented in means and SD.

	mean	SD
hip	117.67 deg	7.99
knee	112.17 deg	4.37
ankle	56.33 deg	10.93

Table 3. Raw average peak torque (Nm) of the hip, knee, and ankle flexors and extensors moving at speeds of 60 deg/s and 180 deg/s presented in means and SD.

			Mean (Nm)	SD
hip	60 deg/s	flexors	85.87	7.89
		extensors	140.33	14.83
	180 deg/s	flexors	62.82	8.84
		extensors	94.91	22.86
knee	60 deg/s	flexors	124.73	19.44
		extensors	201.34	41.48
	180 deg/s	flexors	96.49	16.29
		extensors	141.68	28.86
ankle	60 deg/s	plantar flexors	58.98	12.04
		dorsiflexors	26.44	4.41
	180 deg/s	plantar flexors	28.47	7.83
		dorsiflexors	17.17	2.79

Table 4. Average peak torque (Nm/BW) of the hip, knee, and ankle flexors and extensors moving at speeds of 60 deg/s and 180 deg/s normalized to body weight presented in means and SD.

			Mean (Nm/BWs)	SD
hip	60 deg/s	flexors	0.06	0.01
		extensors	0.11	0.01
	180 deg/s	flexors	0.05	0.01
		extensors	0.07	0.02
knee	60 deg/s	flexors	0.09	0.01
		extensors	0.15	0.03
	180 deg/s	flexors	0.07	0.01
		extensors	0.04	0.01
ankle	60 deg/s	plantar flexors	0.04	0.01
		dorsiflexors	0.02	0.00
	180 deg/s	plantar flexors	0.02	0.01
		dorsiflexors	0.01	0.00

Table 5. Correlation of lower extremity range of motion at the hip, knee, and ankle and ball speed.

		HIP_ROM	KNEE_ROM	ANKLE_ROM
Ball Speed	Correlation Coefficient	.729	.084	-.139
	Significance Level	p = .100	p = .875	p = .793

**. Correlation is significant at the 0.05 level.

Table 6. Correlation of normalized average peak torque of quadriceps, hip extensors, and ankle plantar flexors moving at speeds of 60 deg/s and 180 deg/s and ball speed.

		Quad 60	Quad 180	HExt 60	HExt 180	PF 60	PF 180
Ball Speed	Correlation Coefficient	.287	.554	.307	.142	.328	.753
	Significance Level	p =.581	p =.254	p =.554	p =.789	p =.525	p =.084

**. Correlation is significant at the 0.05 level.

Table 7. List of studies that involve catchers and their number of subjects, age, and experience level.

Study	Number of subjects	Age	Experience level
Dooley et al. 2019	10	17.5+/-5.9	N/A
Fortenbaugh et al. 2010	8	20.6+/-1.4	N/A
Gray et al. 2015	11	18-23	Collegiate
Kawabata et al. 2020	16	21.4+/-3.7	Professional and Collegiate
* Kilcoyne et al. 2015	N/A	N/A	Professional
* Li et al. 2015	22	N/A	Professional
Peng at el. 2015	12	18.9+/-2.8	8.3+/-2.7 years
Plummer et al. 2016	22	14.74+/-4.07	Multiple years

*. Indicates that study only used surveillance data

FIGURES

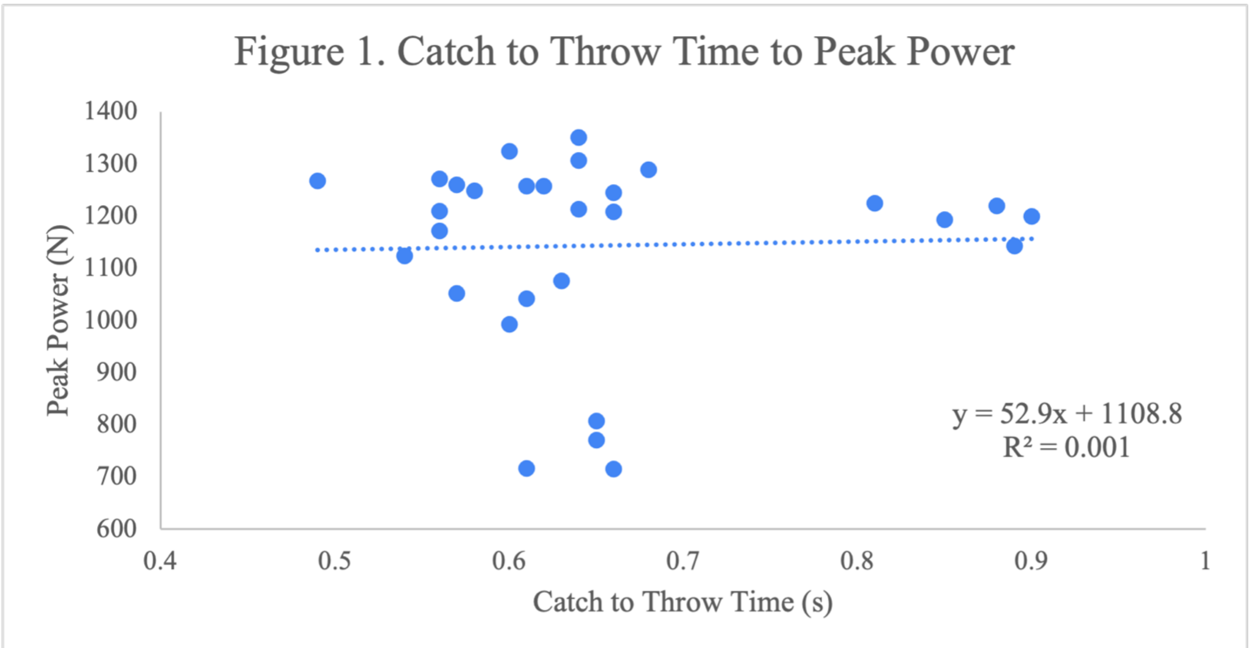

Figure 1. Linear regression of catch to throw time to peak power.

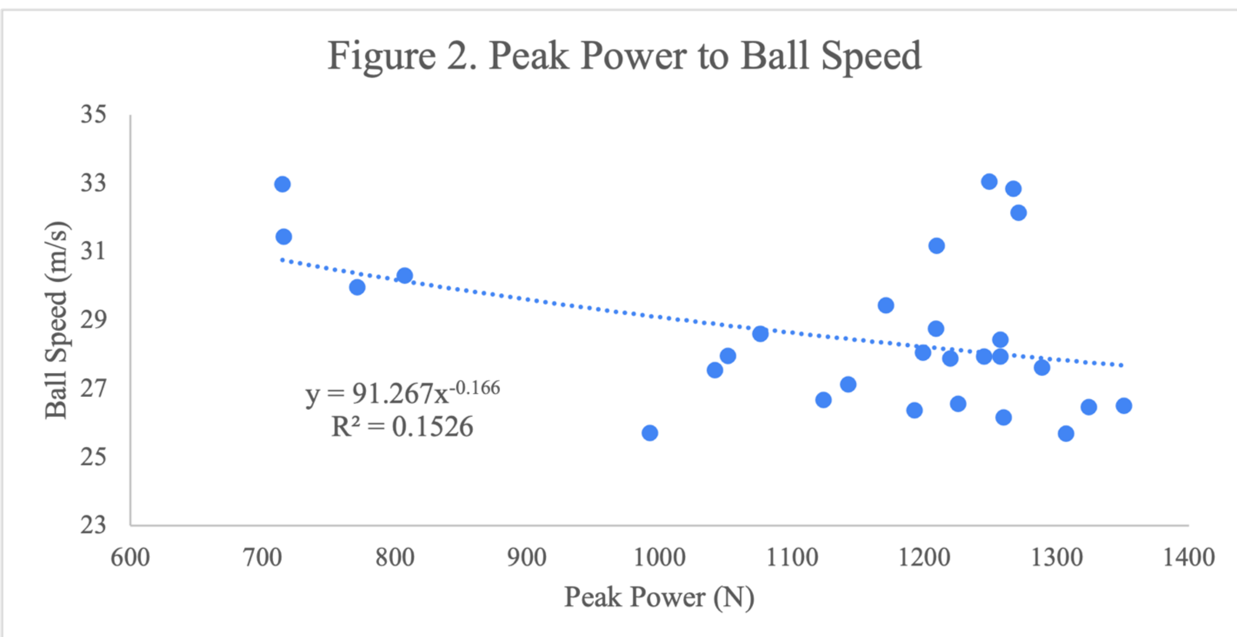

Figure 2. Power regression of peak power to ball speed.

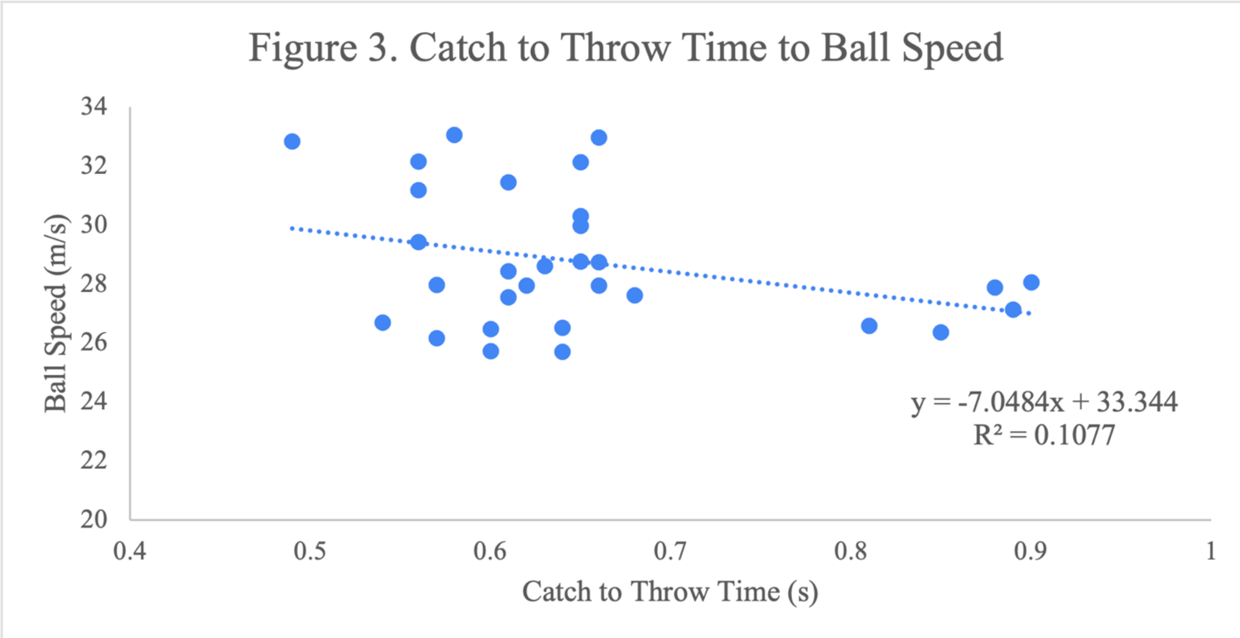

Figure 3. Linear regression of catch to throw time to ball speed.

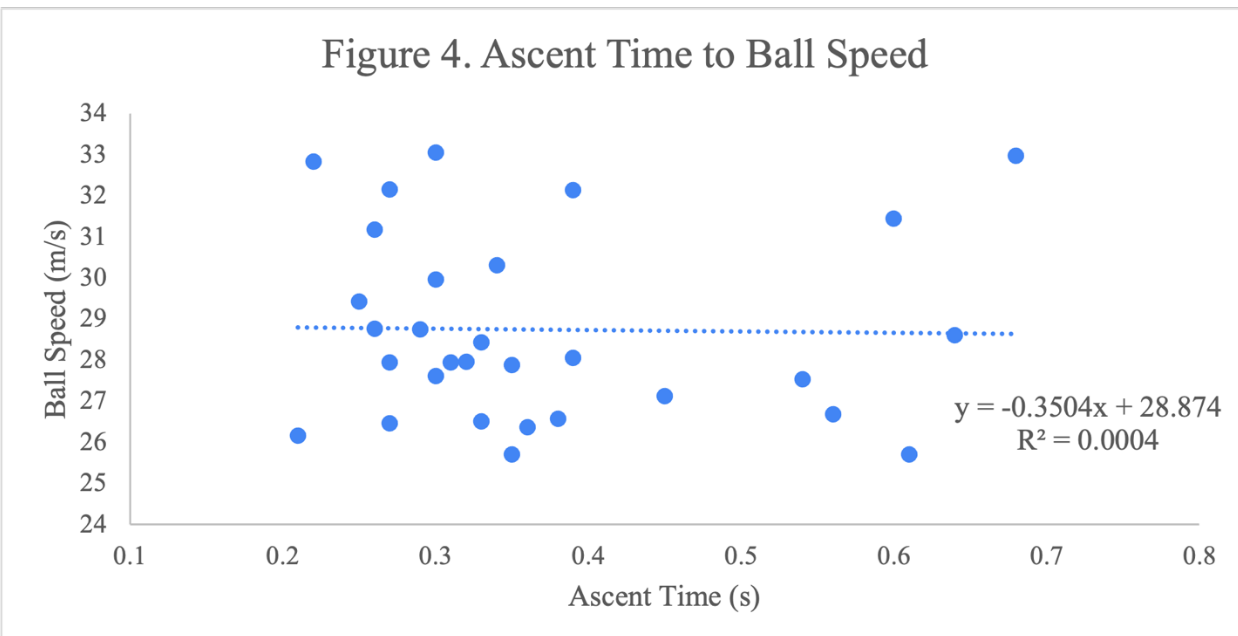

Figure 4. Linear regression of ascent time to ball speed.

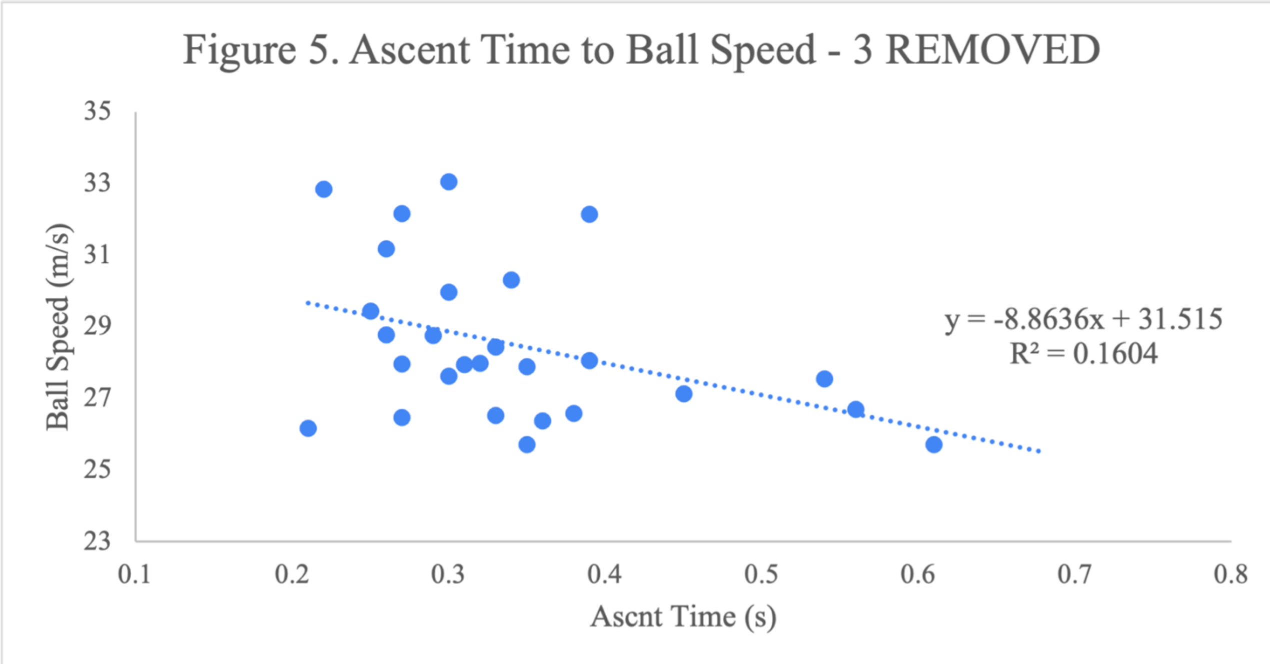

Figure 5. Linear regression of ascent time to ball speed with significant outliers for ball speed removed.

REFERENCES

American College of Sports Medicine, American College of Sports Medicine, Riebe, D., Ehrman, J. K., Liguori, G., & Magal, M. (2018). *ACSM's Guidelines for Exercise Testing and Prescription*. Wolters Kluwer.

Barbero, M., Merletti, R., & Rainoldi, A. (2016). *Atlas of Muscle Innervation Zones*. Springer Publishing.

Barksdale, X. (2011). *Catching-101: The Complete Guide for Baseball Catchers*. AuthorHouse.

Bennett, H.J., Fleenor, K., Weinhandl, J.T., 2018. A normative database of hip and knee joint biomechanics during dynamic tasks using anatomical regression prediction methods. J Biomech 81, 122–131.

Benjamini Y, Hochberg Y. Controlling the false discovery rate: A practical and powerful approach to multiple testing. Journal of the Royal Statistical Society: Series B. 1995;57(1):289-300.

Cotter, J. A., Chaudhari, A. M., Jamison, S. T., & Devor, S. T. (2013). Knee joint kinetics in relation to commonly prescribed squat loads and depths. *Journal of strength and conditioning research*, *27*(7), 1765–1774.

Cressey, E. (2013). Ankle, hip, and thoracic mobility training for catchers. *High Performance Training, Personal Training.*

Davis, R.B., Ounpuu, S., Tyburski, D., Gage, J.R., 1991. A gait analysis data collection and reduction technique. Hum Movement Sci 10, 575–587.

Demers, E., Pendenza, J., Radevich, V., & Preuss, R. (2018). The Effect of Stance Width and Anthropometrics on Joint Range of Motion in the Lower Extremities during a Back Squat. *International journal of exercise science*, *11*(1), 764–775.

Dooley, E., Carr, J., Carson, E., Russell, S. (2019). The effects of knee support on the sagittal lower-body joint kinematics and kinetics of deep squats. *Journal of Biomechanics*, 82, 164-170.

Endo, Y., Miura, M., Sakamoto, M. (2020). The relationship between the deep squat movement and the hip, knee and ankle range of motion and muscle strength. *J. Phys. Ther. Sci.*, 32, 391-394.

Enoka, R. (2008). *Neuromechanics of Human Movement - 4th Edition* (4th ed.). Human Kinetics.

Escamilla, Rafael F., Fleisig, Glenn S., Lowry, Tracy M., Barrentine, Steven W., Andrews, James R. (2001). A three-dimensional biomechanical analysis of the squat during varying stance widths. *Medicine and Science in Sports and Exercise*, 33, 984-998.

Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., & Andrews, J. R. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of biomechanics*, *32*(12), 1371–1375.

Fortenbaugh, D., Fleisig, G.S., & Bolt, B. (2010). Coming down: throwing mechanics of baseball catchers.

Gray, A.M., Ellison, K.T., Smith, B.A. (2015). Effects of using knee savers on lower extremity kinematics in male collegiate baseball catchers during squatting. *Texas Orthopedic Journal*, 1, 51-59.

Hartmann, H., Wirth, K. & Klusemann, M. Analysis of the Load on the Knee Joint and Vertebral Column with Changes in Squatting Depth and Weight Load. *Sports Med* 43, 993–1008 (2013).

Kawabata, K., Urata, T., Fukuda, K., & Tanabe, S. (2020). Time analysis of throwing motions to second base by baseball catchers: comparison of three throwing motions. *International Journal of Sports Science & Coaching*, 15, 677-684.

Kilcoyne, K. G., Ebel, B. G., Bancells, R. L., Wilckens, J. H., & McFarland, E. G. (2015). Epidemiology of Injuries in Major League Baseball Catchers. The American Journal of Sports Medicine, 43(10), 2496–2500.

Kim, S. H., Kwon, O. Y., Park, K. N., Jeon, I. C., & Weon, J. H. (2015). Lower extremity strength and the range of motion in relation to squat depth. *Journal of human kinetics*, *45*, 59–69.

Li, X., Ma, R., Zhou, H., Thompson, M., Dawson, C., Nguyen, J., & Coleman, S. (2015). Evaluation of Hip Internal and External Rotation Range of Motion as an Injury Risk Factor for Hip, Abdominal and Groin Injuries in Professional Baseball Players. *Orthopedic reviews*, *7*(4), 6142.

Marker set guidelines. Marker Set Guidelines - Visual3D Wiki Documentation. (n.d.). https://www.c-motion.com/v3dwiki/index.php/Marker_Set_Guidelines.

Ozkaya, G., Jung, H. R., Jeong, I. S., Choi, M. R., Shin, M. Y., Lin, X., Heo, W. S., Kim, M. S., Kim, E., & Lee, K. K. (2018). Three-dimensional motion capture data during repetitive overarm throwing practice. *Scientific data*, *5*, 180272.

Peng, Y., Lo, K., & Wang, L. (2015). Lower extremity muscle activation and kinematics of catchers when throwing using various squatting and throwing postures. *Journal of Sports Science and Medicine*, 14, 484-493.

Plummer, H. A., & Oliver, G. D. (2016). Descriptive analysis of kinematics and kinetics of catchers throwing to second base from their knees. *Journal of electromyography and* *kinesiology: official journal of the International Society of Electrophysiological Kinesiology*, *29*, 107–112.

Pop time (pop): Glossary. MLB.com. (n.d.). https://www.mlb.com/glossary/statcast/pop-time.

Wu, J. Z., Sinsel, E. W., Carey, R. E., Zheng, L., Warren, C. M., & Breloff, S. P. (2019). Biomechanical modeling of deep squatting: Effects of the interface contact between posterior thigh and shank. *Journal of biomechanics*, *96*, 109333.

Zelle, J., Barink, M., Loeffen, R., De Waal Malefijt, M., & Verdonschot, N. (2007). Thigh-calf contact force measurements in deep knee flexion. *Clinical biomechanics*, *22*(7), 821–826.

APPENDICES

A: Informed Consent Document - Adult

INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: The relationship of strength and mobility with throwing mechanics in baseball catchers.

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

The research on the effects of strength and mobility on transfer time and throwing mechanics in baseball catchers will be conducted in the Neuromechanics Lab and the Student Recreation Center Field.

RESEARCHERS

Dr. Hunter Bennett, a faculty member from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is the principal investigator for this research.

Caleigh Hall, a graduate student from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is an investigator for this research.

Kiara Barrett, a graduate from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is an investigator for this research.

Eva Maddox, a graduate student from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is an investigator for this research.

DESCRIPTION OF RESEARCH STUDY

Several studies have investigated strength, stances, and throwing mechanics in baseball catchers individually. However, no previous research has examined the relationship of strength and mobility with throwing mechanics.

If you decide to participate, you are expected to attend two testing sessions: a 30-minute session at the Neuromechanics Laboratory (SRC 1007) and 1.5-hour session at the Student Recreation Center field. The two testing sessions will be completed on separate days, less than 7-days apart.

For the first session, you will be asked to wear spandex shorts. You will be asked to sit in the dynamometer chair while the researcher's setup the dynamometer to your joints. The researchers will then explain each of the tests to be performed and allow you plenty of time to practice/warmup. You will be asked to perform maximum effort isometric (pre-set position) and isokinetic (pre-set speed) strength tests on the dynamometer for your quads, hamstrings, and glutes. There will be five-repetitions per test.

For the second session, you will be asked to wear spandex shorts and be shirtless. Next, the researchers will apply passive electrodes, small black boxes that record your muscle effort, to the skin above your biceps, triceps, shoulder, glutes, quads, hamstrings, and calves. Prior to placing the electrodes, the researchers will need to shave (if hairy), abrade, and clean the skin above the muscle belly (thickest part of muscle). After placing the electrodes, maximum voluntary contractions will be performed against a stationary resistance (a band). Next, researchers will attach reflective markers to the ends of each of your bones from your feet to your hands (including torso/pelvis). You will then be asked to perform your normal warmup procedures until you are ready to perform standard catcher duties.

After warmup, you will be asked to receive 15 pitches from a pitching machine (at 75 mph) and throw to a person standing at second base. You will be asked to perform these throws in your preferred stance and in a standardized position (feet forward in a deep squat). You will be provided safety gear (helmet, pads).

If you say YES, then your participation will last for 30 minutes–1 hour on the first day of collections at the ODU Neuromechanics Lab, and 1.5-2 hours on the second day of collections at the Student Recreation Center Field. Approximately 50 of other baseball catchers will be participating in this study.

<u>EXCLUSIONARY CRITERIA</u>
To the best of your knowledge, you should not have recent injury to any lower or upper extremity in the previous 3 months that impairs movement and joint function or have a history of surgery in the past 12 months that would keep you from participating in this study. Additionally, you should not participate in this study if you fall outside of the age range of 16-30, you are not a baseball catcher with at least one season of experience at the high-school level, and/or you have not participated as a baseball catcher in an organized setting (e.g. scheduled game) within the past calendar year.

<u>RISKS AND BENEFITS</u>
RISKS: If you decide to participate in this study, then you may face a risk of physical harm or release of confidential information. The researcher tried to reduce these risks by always having an investigator present and nearby the subjects as well as keeping data and information stored in a locked file cabinet or password protected computer. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits for participating in this study.

<u>COSTS AND PAYMENTS</u>

The researchers want your decision about participating in this study to be absolutely voluntary. Persons who volunteer to participate will be entered into a drawing to receive a $50 Amazon gift card, which will be distributed via email. Persons can only win one gift card. A new drawing will commence at intervals of 5 subjects. The first five subjects will have a 1/5 chance of receiving the first card. Then, for those that did not win the first drawing, they will have a chance to receive a gift card after a total of 10 persons have volunteered to subject (1/9 chance of winning), and so on.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

The researchers will take reasonable steps to keep private information, such as questionnaires and medical history, confidential. The researcher will remove identifiers from all identifiable private information collected. Your data will be recorded based on a number/code assigned to you. This number assigned will be used as your subject ID when collecting and storing data within the computer. The questionnaires given to you will be confidential and you will be asked to not write your name on the questionnaires (only the number/code assigned to you). All data will be coded in order to protect your confidentiality. Only the researchers will have access to the coding. Your information will be kept within a computer in a locked room. Upon completing the study, coding material will be destroyed removing any possible link between the data and identifiers. Any computers used to capture data will be password protected and data files will be labeled only using the subject code. Your information will not be used or distributed for future research studies even if identifiers are removed. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact the responsible principal investigator, Dr. Hunter Bennett at 757-683-4387, Dr. Tancy Vandecar-Burdin the current IRB chair at 757-683-3802 at Old Dominion University, or the Old Dominion University Office of Research at 757-683-3460 who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:
Dr. Hunter Bennett: 757-683-4387

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. Tancy Vandecar-Burdin, the current IRB chair, at 757-683-3802, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	**Date**

B: Informed Consent Document – Parent/Guardian

INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: The relationship of strength and mobility with throwing mechanics in baseball catchers.

INTRODUCTION

The purposes of this form are to give you and your child information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

The research on the effects of strength and mobility on transfer time and throwing mechanics in baseball catchers will be conducted in the Neuromechanics Lab and the Student Recreation Center Field.

RESEARCHERS

Dr. Hunter Bennett, a faculty member from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is the principal investigator for this research.

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Eva Maddox, a graduate student from Old Dominion University Darden College of Education and Professional Studies in the department of Human Movement Sciences, is an investigator for this research.

DESCRIPTION OF RESEARCH STUDY

Several studies have investigated strength, stances, and throwing mechanics in baseball catchers individually. However, no previous research has examined the relationship of strength and mobility with throwing mechanics.

If you decide to allow your child to participate, your child is expected to attend two testing sessions: a 30-minute session at the Neuromechanics Laboratory (SRC 1007) and 1.5-hour session at the Student Recreation Center field. The two testing sessions will be completed on separate days, less than 7-days apart.

For the first session, your child will be asked to wear spandex shorts. Your child will be asked to sit in the dynamometer chair while the researcher's setup the dynamometer to your joints. The researchers will then explain each of the tests to be performed and allow you plenty of time to practice/warmup. Your child will be asked to perform maximum effort isometric (pre-set position) and isokinetic (pre-set speed) strength tests on the dynamometer for your quads, hamstrings, and glutes. There will be five-repetitions per test.

For the second session, your child will be asked to wear spandex shorts and be shirtless. Next, the researchers will apply passive electrodes, small black boxes that record your muscle effort, to the skin above your child's biceps, triceps, shoulder, glutes, quads, hamstrings, and calves. Prior to placing the electrodes, the researchers will need to shave (if hairy), abrade, and clean the skin above the muscle belly (thickest part of muscle). After placing the electrodes, maximum voluntary contractions will be performed against a stationary resistance (a band). Next, researchers will attach reflective markers to the ends of each of your child's bones from their feet to hands (including torso/pelvis). Your child will then be asked to perform their normal warmup procedures until they are ready to perform standard catcher duties.

After warmup, your child will be asked to receive 15 pitches from a pitching machine (at 75 mph) and throw to a person standing at second base. Your child will be asked to perform these throws in your preferred stance and in a standardized position (feet forward in a deep squat). Your child will be provided safety gear (helmet, pads).

If you say YES, then your child's participation will last for 30 minutes–1 hour on the first day of collections at the ODU Neuromechanics Lab, and 1.5-2 hours on the second day of collections at the Student Recreation Center Field. Approximately 50 of other baseball catchers will be participating in this study.

<u>EXCLUSIONARY CRITERIA</u>

To the best of your knowledge, your child should not have recent injury to any lower or upper extremity in the previous 3 months that impairs movement and joint function or have a history of surgery in the past 12 months that would keep you from participating in this study. Additionally, your child should not participate in this study if they fall outside of the age range of 16-30, your child is not a baseball catcher with at least one season of experience at the high-school level, and/or they have not participated as a baseball catcher in an organized setting (e.g., scheduled game) within the past calendar year.

<u>RISKS AND BENEFITS</u>

RISKS: If you decide to allow your child to participate in this study, then your child may face a risk of physical harm or release of confidential information. The researcher tried to reduce these risks by always having an investigator present and nearby the subjects as well as keeping data and information stored in a locked file cabinet or password protected computer. And, as with any research, there is some possibility that your child may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits for participating in this study.

<u>COSTS AND PAYMENTS</u>

The researchers want your decision about participating in this study to be absolutely voluntary. Persons who volunteer to participate will be entered into a drawing to receive a $50 Amazon gift card, which will be distributed via email. Persons can only win one gift card. A new drawing will commence at intervals of 5 subjects. The first five subjects will have a 1/5 chance of receiving the first card. Then, for those that did not win the first drawing, they will have a chance to receive a gift card after a total of 10 persons have volunteered to subject (1/9 chance of winning), and so on.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

The researchers will take reasonable steps to keep private information, such as questionnaires and medical history, confidential. The researcher will remove identifiers from all identifiable private information collected. Your child's data will be recorded based on a number/code assigned. This number assigned will be used as their subject ID when collecting and storing data within the computer. The questionnaires given will be confidential and you will be asked to not write any names on the questionnaires (only the number/code assigned). All data will be coded in order to protect your confidentiality. Only the researchers will have access to the coding. Information will be kept within a computer in locked room. Upon completing the study, coding material will be destroyed removing any possible link between the data and identifiers. Any computers used to capture data will be password protected and data files will be labeled only using the subject code. Your information will not be used or distributed for future research studies even if identifiers are removed. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision to allow your child to participate will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact the responsible principal investigator, Dr. Hunter Bennett at 757-683-4387, Dr. Tancy Vandecar-Burdin the current IRB chair at 757-683-3802 at Old Dominion University, or the Old Dominion University Office of Research at 757-683-3460 who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study,

and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:
Dr. Hunter Bennett: 757-683-4387

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. Tancy Vandecar-Burdin, the current IRB chair, at 757-683-3802, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Note: By signing below, you are telling the researchers YES, that you will allow your child to participate in this study. Please keep one copy of this form for your records.

Your child's name (please print): ______________________________

Your name (please print): ______________________________

Relationship to child (please check one): Parent: _______ **Guardian:** _____

Your Signature: ______________________________
Date: ______________________________

INVESTIGATOR'S STATEMENT: I certify that this form includes all information concerning the study relevant to the protection of the rights of the subjects, including the nature and purpose of this research, benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human research subjects and have done nothing to pressure, coerce, or falsely entice the parent to allowing this child to participate. I am available to answer the parent's questions and have encouraged him or her to ask additional questions at any time during the course of the study.

Researcher's Signature: ______

Date:

____

C: Assent Form

ASSENT FORM

BASEBALL CATCHER STUDY

My name is Hunter Bennett. I work at Old Dominion University.

I am asking you to take part in a research study because I am trying to learn more about baseball catchers. I want to learn about the effects of strength and mobility on your throwing style.

If you agree, you will be asked to attend two testing sessions: a 30-minute and a 1.5-hour session at the Neuromechanics Laboratory. For the first session, you will be asked to perform strength tests on each leg. For the second session, you will be asked to throw 15 pitches into a net in front of you from a catching stance.

You do not have to be in this study. No one will be mad at you if you decide not to do this study. Even if you start, you can stop at any time if you want. You may ask questions about the study.

If you decide to be in the study, I will not tell anyone else what you say or do in the study. Even if your parents or coaches ask, I will not tell them about what you say or do in the study.

Signing here means that you have read this form or have had it read to you and that you are willing to be in this study.

Signature of subject____

Subject's printed name ____

Signature of investigator____

Date___________________________

D: Medical History and Physical Activity Questionnaire

Medical History & Physical Activity Questionnaire

Please answer the following questions to the best of your ability:

Sex:

☐Male ☐Female

Race/ethnicity *(please check all that apply)*:

☐American Indian/Alaska Native

☐Asian

☐Native Hawaiian or other Pacific Islander

☐Hispanic or Latino

☐Black or African American

☐White

Which leg would you use to kick a ball?

☐Right ☐Left

Which arm would you use to throw a ball?

☐Right ☐Left

To be completed by investigator:

Age:________ yr Height: ________ m Mass: ________ kg

Medical History Questionnaire

For your safety, a list of conditions that would make you unable to participate in this study has been prepared. Please read this list carefully and consider whether any of the conditions apply to you. If any of these conditions are true for you, you will not be able to participate in this study. For each condition, please indicate "yes" or "no" if this is true or not for you.

☐Yes ☐No Are you currently physically active at a moderate level for at least 30 minutes/day, at least 3 days of the week?

☐Yes ☐No Do you have a medical condition that may impair your balance performance (i.e. concussion, neurological impairments, etc)?

☐Yes ☐No Are you taking medications/drugs that may make you dizzy or make you tired (i.e. cold medications, sleeping medications, muscle relaxants)?

☐Yes ☐No Have you ever had a lower extremity injury that caused you to decrease the amount of physical activity you undertake? If yes, please complete the following:

☐Yes ☐No Hip injury(ies)
If yes, approximately how many injuries?__________________________

☐Yes ☐No Knee injury(ies)
If yes, approximately how many injuries?
____

☐Yes ☐No Ankle/foot injury(ies)
If yes, approximately how many injuries?
____

☐Yes ☐No Have you had, in the last 6 months, a lower extremity injury that caused you to decrease the amount of physical activity you undertake?

☐Yes ☐No Do you currently have any lower extremity pain or injury(ies)?

☐Yes ☐No Have you ever had major lower extremity orthopedic surgery/joint replacement?

Physical Activity Questionnaire

1. Select the highest level of baseball you have participated as a catcher in (e.g. played on a team for):

   ☐High School ☐College ☐Club

   Name of High School:______________ Name of College:_______________ Club Name:_______________

   Years:__________ Years:__________ Years:__________

2. How many years have you been a catcher:

   _____ including little/prep leagues

_____ only for a traveling club type

_____ only for a high school

_____ only for a college

3. On average, how many days a week have you participated in catching for practice or games in the past 12 months?

_____ days per week

Curriculum Vitae

Curriculum Vita

Caleigh D. Hall, B.S.

Old Dominion University
Department of Human Movement Sciences
chall028@odu.edu

<u>Education</u>:

Old Dominion University
M.S. (Exercise Science) – May 2022
Thesis: *"The Relationship of Strength, Mobility, and Performance Variables on Throwing Speed in Baseball Catchers."*

East Carolina University
B.S. (Exercise Physiology) – May 2020

<u>Relevant Coursework</u>:

Exercise Physiology	Fall 2020
Clinical Exercise Testing and Prescription	Spring 2021
Strength and Conditioning Applications	Spring 2021
Nutrition for Sports Health	Spring 2021
Advanced Biomechanics	Fall 2020
MATLAB Programming in Biomechanics	Spring 2022

<u>Professional Experience</u>:

Research:

Old Dominion University, Neuromechanics Laboratory
Graduate Research Assistant — 2021-Present

East Carolina University, Biomechanics Laboratory
Student Intern — 2019-2020

Administrative:

Old Dominion University, Innovative Technology
Graduate Administrative Assistant — 2020-2021

East Carolina University, National Biomechanics Day
Administrative Assistant — 2019-2019

Current Research Projects

"The Relationship of Strength, Mobility, and Performance Variables on Throwing Speed in Baseball Catchers."

Professional Memberships:

International Women in Biomechanics 2021-Present

Computer Skills:

Microsoft Word, Excel, and PowerPoint
Vicon Motion Capture System
Visual 3D
Matlab
SPSS