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How gender and task difficulty affect a sport-protective response in young adults

David B. Lipps, MS, **James T. Eckner, MD MS**, **James K. Richardson, MD**, and **James A. Ashton-Miller, PhD**

Abstract

We tested the hypotheses that gender and task difficulty affect the reaction, movement, and total response times associated with performing a head protective response. Twenty-four healthy young adults (13 females) performed a protective response of raising their hands from waist level to block a foam ball fired at their head from an air cannon. Participants initially stood 8.25 m away from the cannon ('low difficulty'), and were moved successively closer in 60 cm increments until they failed to block at least 5 of 8 balls ('high difficulty'). Limb motion was quantified using optoelectronic markers on the participants' left wrist. Males had significantly faster total response times ($p = 0.042$), a trend towards faster movement times ($p = 0.054$), and faster peak wrist velocity ($p < .001$) and acceleration ($p = 0.032$) than females. Reaction time, movement time, and total response time were significantly faster under high difficulty conditions for both genders ($p < .001$). This study suggests that baseball and softball pitchers and fielders should have sufficient time to protect their head from a batted ball under optimal conditions if they are adequately prepared for the task.

INTRODUCTION

The upper extremities are of critical importance in protecting the head and torso from impact by an approaching object (DeGoede, Ashton-Miller, Liao, & Alexander, 2001). This type of protective maneuver is commonly performed in sports such as baseball and softball when pitchers and infielders react to protect themselves from a rapidly approaching batted ball. When an athlete is unable to successfully block or catch a ball that has been hit directly at their head or torso the results can be devastating. Epidemiologic studies have shown that batted balls account for 20% of all injuries in Little League baseball, 30% of game injuries in collegiate baseball pitchers and 22% of game injuries in collegiate softball pitchers (Dick et al., 2007; Marshall, Hamstra-Wright, Dick, Grove, & Agel, 2007; Nicholls, Elliott, & Miller, 2004). Among catastrophic high school and collegiate baseball injuries recorded between 1981 and 2002, a pitcher or fielder being hit by a batted ball was the second most common injury mechanism (Boden, Tacchetti, & Mueller, 2004). Batted balls accounted for 41% of all catastrophic injuries in this sample, in many cases resulting in coma, serious disability, or death.

Many factors influence an athlete's ability to protect him or herself from a rapidly approaching ball. One of the most obvious of these is the speed with which the ball has been hit which, for a given distance, dictates the time available to the pitcher or fielder before being struck. The speed of the ball off the bat is, in turn, affected by the mechanical properties of the bat as well as the bat speed at the time of contact (Ashton-Miller, Carroll, Johnson, & Nathan, 2004). Aluminum bats, for example, can yield a greater batted ball speed than wood bats because they can store and return more energy from the ball-bat collision than wood bats (Nathan, 2003) and because their lower moment of inertia allows for greater bat speed (Crisco, Greenwald, Blume, & Penna, 2002).

A number of studies have estimated the time a batted ball takes to reach the pitcher. In baseball, for example, Cassidy and Burton (Cassidy & Burton, 1989) estimated that a pitcher has 400 ms before being struck by a batted ball. However the time available depends upon the type of bat used. Computer models suggest that a baseball pitcher may only have 282 ms to respond to a baseball hit from an aluminum bat, but 377 ms when a wood bat is used (Nicholls, Miller, & Elliott, 2005). In softball, a pitcher has been estimated to have 361 ms to respond to a ball batted by a composite bat (McDowell & Ciocco, 2005). All of these studies have focused on the time a pitcher has available to react before being struck by a batted ball, rather than his or her ability to actually react in time.

In addition to the time the ball takes to reach the pitcher or fielder, another primary determinant of the athlete's success in protecting him- or herself is the ability to rapidly block, catch, or dodge the incoming ball. While there is a large body of literature investigating the relationship between reaction time and sport performance in general, little research has directly examined an athlete's ability to perform a protective maneuver relevant to a batted ball sport. Owings et al. (Owings, Lancianese, Lampe, & Grabiner, 2003) studied the reaction times and glove movement velocities of baseball and softball players aged 8-16 years under simulated game conditions to characterize the influence of ball velocity, attention, and age during a simulated catch of a ball directed towards the athlete's chest. Reaction times and glove movement velocities were significantly faster at higher ball velocities and when the athletes were not required to perform an attention-splitting task. In addition, the older participants had significantly faster reaction times and glove velocities. There was an interaction between gender and task difficulty for reaction time with girls' reaction times being more adversely affected by an attention-splitting task, but there was no overall gender effect. Young et al. (Young, Trachtman, Scher, & Schmidt, 2006) studied the movement onset times and glove velocities of high school and college baseball pitchers in response to a simulated line drive projected at their heads immediately after delivering a typical baseball pitch. College pitchers initiated movement faster and demonstrated greater glove velocities than high school pitchers, but this trend reached statistical significance only for movement onset times.

Previous work in a non-sport context has shown age, gender, and task difficulty affect the hand movement times in seated participants blocking a large object approaching at head level (DeGoede, et al., 2001). However, to our knowledge the effect of gender and task difficulty on a healthy, young individual's total response time, reaction time, and movement time when protecting the head from an incoming ball in a simulated sport environment has never been studied. We therefore investigated the protective responses of healthy young adults using their upper extremities to block a spherical foam projectile aimed at their head under high difficulty and low difficulty conditions. These responses represent a "best case scenario" in which the participant starts in a ready position and is focused solely on performing a stereotyped head protective maneuver in response to a uniform and predictable stimulus in the absence of any distraction. The results of this "best case scenario" laboratory-based study can be applied to future field studies in athletes investigating pitcher and fielder safety, and to develop strategies for improving player safety in batted ball sports. We tested the primary hypothesis that gender and task difficulty would affect the fastest total response time, and its associated reaction time and movement time, of participants performing a head-protective response in a simulated sport environment. We also tested the secondary hypothesis that blocking performance (expressed by maximum linear hand acceleration and peak linear hand velocity) would also be influenced by gender and task difficulty.

METHODS

Participants

Thirteen healthy adult females (mean age= 26.1 ± 8.6 yrs, height = 168.6 ± 6.5 cm, weight = 69.7 ± 12.1 kg) and 11 healthy adult males (mean age= 28.5 ± 8.3 yrs, height = 178.7 ± 6.9 cm, weight = 78.8 ± 8.8 kg) were recruited via advertisements posted at local recreational facilities. The sample size was based on an independent samples, two-tailed power calculation using $\alpha = 0.05$ and 80% power, which showed that 11 males and 11 females would be required to detect a gender difference in mean total response time under the high perceived threat condition (effect size = 1.15, based on pilot results from a sample of 3 males and 3 females). Participants were excluded for self-report of any acute or chronic medical conditions that might interfere with safety or performance. The testing procedures were approved by the Institutional Review Board at the authors' institution and all participants gave informed written consent prior to participating in this study. Subjects simultaneously participated in a study examining the relationship between a clinical measure of manual reaction time and the head-protective response reported here (Eckner, Lipps, Kim, Richardson, & Ashton-Miller, 2010).

Experimental Methods

Participants were equipped with a protective face mask and chest protector. A custom-built air cannon fired a bright yellow foam tennis ball (Gamma Sports, Pittsburgh, PA, 42.5 g weight, 7 cm diameter) at a mean velocity of 21 m/s at the subject's head. To improve accuracy, a sabot was used to transport the foam ball down the cannon barrel without spinning. The location of the air cannon was fixed throughout testing, but the distance between the participant and the air cannon was incrementally decreased to increase task difficulty. Subjects were instructed to begin each trial in a "ready position" with both hands resting on their hips, feet shoulder-width apart, and knees slightly flexed. They were instructed to move both hands in front of their face to block the foam ball as quickly as possible as soon as it was fired from the air cannon. Before each trial, the participant indicated when he or she was prepared for the cannon to fire. The air cannon was then manually activated by a member of the study team, and it fired the ball after a random time delay of up to three seconds. The purpose of the time delay was to limit the test participant's ability to anticipate the time of ball delivery.

To test the effect of task difficulty on total response time, reaction time, and movement time during the sport-protective response, participants were tested under the low difficulty and high difficulty conditions. Prior to low difficulty testing, participants performed four practice trials to become comfortable with the experiment and to fine-tune the aim of the air cannon. Following the practice trials, participants completed up to 8 trials under the low difficulty testing condition at a distance of 8.25 m from the muzzle of the air cannon, corresponding to the maximum available distance within the laboratory. Once the participant successfully blocked the ball for 5 trials, he or she was repositioned 60 cm closer to the air cannon. Two practice trials were completed at the new distance, followed by up to 8 recorded trials. Each time the participant successfully blocked 5 trials he or she was again repositioned 60 cm closer to the air cannon. The high difficulty testing condition was defined as the shortest distance (4 – 6 m) from the air cannon where the participant failed to block over 50% of a set of 8 trials (i.e., at least 5 successful blocks). The mean (± 1 SD) horizontal distance between the participants and the air cannon under the high difficulty condition was 5.08 ± 0.72 m for males and 5.89 ± 0.74 m for females. Performance under the high difficulty condition was felt to represent each participant's maximal blocking ability.

A trial was classified as a successful ‘block’ when the participant did not have to move their feet, moved both hands above the plane of their sternoclavicular joint, and at least one of their hands made contact with the ball. Trials were classified as ‘misses’ if the participant’s hand(s) did not make contact with the ball and it struck the helmet or a semicircular piece of cardboard that was attached to the helmet back extending 15 cm beyond the profile of the helmet in the frontal plane. In trials where the cannon fired inaccurately (i.e., the trajectory of the ball was greater than 15 cm away from the helmet, as determined by its failure to make contact with the participant’s hand(s), the helmet, or the cardboard target), or where the participant did not move both hands up to block the ball, the trial was repeated.

For each trial, data collection began when the foam ball passed through a light gate (Banner Engineering Corp., Minneapolis, MN) located at the muzzle of the air cannon. Optoelectronic markers were placed over the ulnar styloid on the left wrist and on the chest protector over the left sternoclavicular joint. An Optotrak Certus (Northern Digital Inc., Waterloo, Ontario, Canada) motion capture system measured the three-dimensional motion of the left wrist relative to the sternoclavicular joints from a left lateral view with a sampling frequency of 1 kHz and a resolution of 0.1 mm.

Data Analysis

Optoelectronic and light gate signals were analyzed using MATLAB (2009b, The Mathworks Inc., Natick, MA). The position data from the optoelectronic markers were digitally low-pass filtered using a fourth-order Butterworth Filter with a 50 Hz cutoff frequency. Linear velocity and linear acceleration in the sagittal plane were then calculated from the position data using a 5-point numerical differentiation. The initiation of the protective motion was defined as the instant the magnitude of the acceleration vector (i.e., square root of sum of squares) of the left wrist exceeded 3 SD of the mean acceleration at rest. The completion of the protective motion was defined as the instant the left wrist marker broke the horizontal sternoclavicular reference plane. Reaction time was defined as the interval between the ball exiting the muzzle of the air cannon and the initiation of the protective motion. The time between the initiation and completion of the protective motion was defined as movement time. Total response time was defined as the sum of the reaction time and movement time. For each participant, the trial with the shortest total response time (along with the corresponding reaction time and movement time for that trial) under each testing condition was included in the analysis. The rationale for choosing the fastest total response time from 8 trials, rather than the mean total response time, was to determine the maximal blocking capabilities of each participant for each level of task difficulty (DeGoede et al., 2001). Fastest total response time was highly correlated with mean total response time ($R^2 = 0.957$). The maximum linear acceleration and peak linear velocity during each participant’s best trial were also measured and included in a secondary analysis.

Statistical Analysis

Statistical analyses were conducted using PASW Statistics 17.0 (SPSS Inc., Chicago, IL). The normality of the data was checked visually with histograms and statistically with the Shapiro-Wilk test. The primary hypothesis was tested with a 2 × 2 two-way analysis of variance (ANOVA) examining the effects of gender and task difficulty on each participant’s fastest total response time and the corresponding reaction time and movement time for that trial. The secondary hypothesis was tested with a 2 × 2 two-way ANOVA examining the effects of gender and task difficulty on maximum linear acceleration and peak linear velocity. A p value less than 0.05 was considered statistically significant.

RESULTS

A significant gender effect was present for total response time (F(1, 44) = 4.37, p = 0.042), with a trend towards significance for movement time (F(1, 44) = 3.93, p = 0.054). There was no significant gender effect for reaction time (F(1, 44) = 0.86, p = 0.358). In contrast, there was a highly significant effect for difficulty level on total response time (F(1, 44) = 52.73, p < 0.001), reaction time (F(1, 44) = 40.39, p < 0.001), and movement time (F(1,44) = 21.69, p < 0.001). There were no significant gender-by-task difficulty interactions for any of the three measurements (total response time: F(2, 44) = 1.334, p = 0.254; reaction time: F(2, 44), = 0.530, p = 0.470; movement time: F(2, 44) = 0.824, p = 0.369). Total response time was 11.5% faster for males than females under the high difficulty condition. The fastest female total response time under the high difficulty condition (212 ms) was similar to the average male total response time (214 ms). Overall, males significantly improved their mean (± 1 SD) reaction time under the high difficulty condition by 34 (20) ms and movement time by 39 (35) ms as compared to the low difficulty condition. In comparison, females improved their reaction time by 27 (22) ms and movement time by 26 (24) ms. These results are summarized in Table 1 and Figure 1.

The mean vertical distance the wrist traveled during the simulated sports-response for all participants was 40 ± 5 cm. There were corresponding kinematic findings associated with the above gender effects in reaction time. For example, a secondary ANOVA demonstrated significant gender and task difficulty effects for peak linear velocity (F(1, 44) = 30.99, p < 0.001 and F(1, 44) = 14.14, p < 0.001, respectively) and maximum linear acceleration (F(1, 44) = 4.89, p = 0.032 and F(1, 44) = 11.48, p=0.001, respectively), with no gender by task difficulty interactions (F(2, 44) = 0.671, p = 0.417 for peak linear velocity and F(2,44) = 0.444, p = 0.590 for maximum linear acceleration). In females under high difficulty testing, peak linear velocity (Figure 2) was 18.2% lower and maximum linear acceleration (Figure 3) was 12.3% lower than males. The greater peak linear velocities and maximum linear accelerations of the wrist in men appear to explain the observed trend towards a gender difference in movement time and the significant gender difference in total response time.

DISCUSSION

This is the first study to investigate the effects of gender and task difficulty on the total response time, and its associated reaction time and movement time components, associated with an individual’s maximal performance during a head-protective response in a simulated sport environment. The main finding was that maximal protective total response time was faster in males than females. This finding was driven by a trend towards a faster movement time in males than females. Furthermore, Total response time, reaction time, and movement time were each significantly faster under high difficulty than low difficulty testing conditions. This finding was expected since participants were forced to react more quickly under the high difficulty testing conditions as a result of their closer proximity to the air cannon. Under high difficulty conditions, males demonstrated a nearly 30 ms faster total response time than females. Most of this difference was attributable to movement time, which correlates with males’ significantly greater maximum wrist accelerations and peak velocities.

The gender differences in movement time and total response time are likely a result of known gender differences in strength and rate of moment generation. For example, healthy young men demonstrated greater strength than women while performing shoulder abduction and shoulder flexion, both isokinetically and isometrically (Danneskiold-Samsoe et al., 2009). In addition, we have recently shown a 23 ms gender difference in the mean reaction time off the starting blocks for elite sprinters at the 2008 Beijing Olympics (Lipps, Eckner, Richardson, Galecki, & Ashton-Miller, 2009). Men produced quicker starting block reaction times than women partially due to women taking longer to generate equivalent ankle plantarflexion moments (Thelen, Schultz, Alexander, & Ashton-Miller, 1996), largely due to their muscle mass comprising a lower percentage of total body mass (Janssen et al., 2000). It is therefore reasonable to speculate that these systematic differences in motor function allowed the males to raise their upper extremities more rapidly, thereby explaining the significantly shorter movement in men. This finding suggests that upper limb strengthening interventions may be an effective strategy for improving athletes' protective response times. An alternative explanation for the observed gender difference in total response time and movement time is the possibility of different speed-accuracy tradeoff strategies between male and female participants. In support, men were faster than women at taking aim, while the women were more accurate during a computerized aiming task (Barral & Debu, 2004). Thus females may have been more concerned than males with making an accurate primary movement that completely blocked the ball rather than merely deflecting it.

Given the standard dimensions of a baseball diamond, the approximate stride length of a pitcher during follow-through (Escamilla, Fleisig, Zheng, Barrentine, & Andrews, 2001), assuming faster batted ball speeds when struck with an aluminum bat (Crisco, et al., 2002) and an air drag coefficient of 0.35 (Kensrud & Smith, 2010), we estimate that a baseball pitcher has a minimum of 406 ms to move their hands in front of their head to protect it from a batted ball (Appendix A). A similar model for softball predicts that a softball pitcher has only 296 ms to protect their head. The results of this study, therefore, suggest that healthy, active men and women should be able to generate a maximal protective response fast enough to shield their heads from a batted ball under game conditions. The fact that pitchers and infielders do sustain injuries as a result of being struck by line drives demonstrates that other factors are in play. Similar to the work of DeGoede et al. (DeGoede, et al., 2001), this study investigated optimal protective responses to provide an understanding of the peak capabilities of healthy, young adults under ideal conditions. Participants were aware that the ball would be projected towards their head on every trial and started the task in a "ready position" with their hands resting on their hips prepared to perform a stereotyped blocking motion without any extraneous distraction. During an actual baseball or softball game, the pitcher or infielder is unlikely to be actively preparing for a ball to be batted directly at their head following every pitch, and is likely to be diverting some of their attention to executing the pitch and/or anticipating base runner and fielding scenarios. In the case of the pitcher, he or she may have the added disadvantage of having to initiate a protective response during their follow-through, when either or both of their hands are below hip level.

Increased task difficulty had a clear effect on reaction time, movement time, and total response time in participants of both genders, with faster performances observed under the high difficulty conditions. This suggests that decision making and response initiation by the central nervous system (reaction time) and the subsequent motor performance of the response (movement time, linear acceleration and velocity of the wrist), are both influenced by task difficulty. These results corroborate and extend those of Owings et al. (Owings, et al., 2003), who found that reaction times and glove velocities were significantly faster during trials in which an incoming ball was projected at 33.5 m/sec as compared to 26.8 m/sec. These data suggest that participants do not universally give their best cognitive or motor performance, even in a relatively distraction free environment. Given that the differential level of task difficulty between the high difficulty and low difficulty conditions was readily apparent due to the change in distance between the participant and the air cannon, it is unknown whether similar results would be obtained if participants were unable to anticipate the difficulty level of any given trial, as is the case during competition. If slower protective responses are the result of a lower *anticipated* task difficulty level, as opposed to a lower *actual* difficulty level, then coaching interventions could potentially be applied in which pitchers and fielders are taught to anticipate the need to perform a highly challenging protective response after every pitch.

The strength of the conclusions drawn from this study must be tempered by its limitations which relate, primarily, to the differences between the experimental protocol and game conditions. First, although we tested young, active individuals from recreational facilities, participation in organized baseball or softball was not a specific inclusion criterion. This is relevant given prior studies which have shown baseball players to be faster than non-athletes when performing go/no-go reaction time tasks (Kida, Oda, & Matsumura, 2005; Nakamoto & Mori, 2008). Baseball expertise will improve the ability to detect a moving target and inhibit an incorrect response (Nakamoto & Mori, 2012), so it would be anticipated that such athletes would show faster total response time’s than those from our study sample. If this were the case, it would further emphasize the point that baseball and softball injuries due to a pitcher being struck by a batted ball are not simply a result of insufficient time to perform a protective response. Rather one can surmise that injuries are related to longer response times due to (a) indecision as to which avoidance strategy to use (i.e., dodge or manually block the ball), or (b) divided attention (Mendelson, Redfern, Nebes, & Richard Jennings, 2010). Finally, this study is unlikely to replicate the mental and physical fatigue a baseball or softball pitcher will undergo over the course of a game. The onset of sensorimotor system fatigue of the upper extremity occurs in 62 throws on average in collegiate baseball players (Tripp et al., 2007).

A second study limitation is that participants were not blinded to difficulty associated with the blocking task, as it was apparent based on their distance from the cannon. This contrasts with game conditions, during which the difficulty associates with blocking or catching a batted ball following any given pitch is unpredictable. Therefore it would be valuable to determine whether the trend of improved protective response performance under the high difficulty condition varies when task difficulty is unknown prior to each trial. In addition, the order of high difficulty and low difficulty conditions was not randomized. However, order effects in the case of this experiment are unlikely because previous studies have also shown faster responses with increased task difficulty (Owings et al., 2003).

A third limitation is that we focused only on a single, stereotyped protective response, where both hands move simultaneously towards the ball. While in peak velocity and maximum acceleration was only recorded for the left wrist, the difference between hands will be minimal ed due to the simultaneous hand movement. This protective response contrasts to the situation in game play, during which players have the option of dodging a batted ball, or combining a blocking/catching and dodging strategy. The observed effects of gender and task difficulty identified in this study may not translate to these alternative maneuvers.

A fourth potential limitation relates to the cannon providing a dual stimulus, the ball emerging from the muzzle and a loud noise just prior. The total response time’s reported are based on the visual stimulus defined by the ball passing the muzzle light gate. To estimate auditory stimulus lead time, a microphone was mounted on one participant’s helmet. It detected the sound of the cannon firing 5-17 ms before the ball arrived at the muzzle light gate, depending on the distance from the participant to cannon, and was relatively consistent making systematic bias unlikely. However, an auditory cue is present under baseball or softball game conditions as a result of the bat striking the ball. Finally, it is unlikely that either the minor weight of a fielder’s mitt or the short additional distance that the hand needs to traverse from the sternoclavicular joint to the face would alter the significance of our findings in practice.

In conclusion, we found a gender difference in movement time and total response time, as well as wrist velocities and accelerations, which may be explained by greater muscular strength in males or, possibly, by the use of different gender-specific strategies for targeting and blocking a ball. We also found that increasing the difficulty of the task, by moving the participant closer to the air cannon, produced faster total response time, reaction time, movement time, wrist velocity, and wrist acceleration for both genders. Adult males and females both completed the head-protective response during the high difficulty test faster than is required for a baseball or softball pitcher (or fielder) to protect their head from a batted ball at distances of 18.7 and 13.1 meters, respectively, before being struck. Given these findings, useful preventative strategies may include strengthening the upper limbs and coaching interventions to teach a pitcher or fielder to anticipate the need to generate a maximally challenging protective response after every pitch.

APPENDIX A: MODEL TO PREDICT AVAILABLE REACTION TIME IN BASEBALL AND SOFTBALL PITCHERS

In order to predict the available reaction time a baseball or softball pitcher has to respond to a ball batted at their head, a 2-D projectile motion model with air resistance was developed in MATLAB (2009b, The Mathworks Inc., Natick, MA) using the ode45 ordinary differential equation solver. Air resistance on a baseball was modeled by calculating the drag force, $F_{d,}$, at each time step:

$$F_d = \left(C_d \cdot A \cdot \rho \cdot v^2\right)/2 \quad [1]$$

The drag coefficient (C_d) of a baseball was assumed to be 0.35 (Kensrud & Smith, 2010), the cross-sectional area (A) of a baseball was assumed to be 43 cm^2, the density of air (ρ) was assumed to be 1.2 kg/m^3, and v represents the velocity of the ball in the x and y direction at each time step during the numerical integration. The initial conditions included the ball being hit from a height of 1.2 m; the batted ball speed was 44.7 m/s, a ball velocity achieved with an aluminum baseball bat for 37% of all hits (Crisco, et al., 2002); the ball had a launch angle of 3.5 degrees off the bat to simulate a line drive; and the ball has no angular momentum. The mass of the baseball was assumed to be 0.145 kg. The state function for the numerical integration solved for the ball acceleration (a) in the x and y direction at each time step was:

$$a_x = -F_{d,x}/m \quad [2]$$

$$a_y = -g - \left(F_{d,y}/m\right) \quad [3]$$

The pitcher's mound on a baseball diamond is located 18.7 m from home plate. A baseball pitcher has an approximate stride length of 1.5 m (Escamilla, et al., 2001), so the pitcher will be 17.2 m from home plate when the ball is hit. The numerical integration was stopped when the horizontal distance the ball traveled reached 17.2 m. Using this model, the available reaction time for a baseball pitcher was found to be 406 ms.

By adjusting the model parameters, the simulation can also predict the available reaction time of a softball pitcher. The drag coefficient of a 97 mm softball was approximately 0.3 (Kensrud & Smith, 2010), the cross-sectional area of a softball was 74 cm^2, and the mass of a softball was 0.198 kg. The initial velocity of the softball was assumed to be 40.8 m/s, the average batted ball speed measured in McDowell and Ciocco (McDowell & Ciocco, 2005). A softball pitcher should be 11.6 m from home plate when the ball is hit since the pitcher's mound is 13.1 m away from home plate and the softball windmill pitching motion has an approximate stride length of 1.5 m (Werner, Jones, Guido, & Brunet, 2006). The model predicts a softball pitcher will only have 296 ms to respond to a batted ball. The predicted available reaction time for a softball pitcher is therefore 110 ms less than the available reaction time for a baseball pitcher, primarily due to their being closer to the batter at the instant of bat-ball contact.

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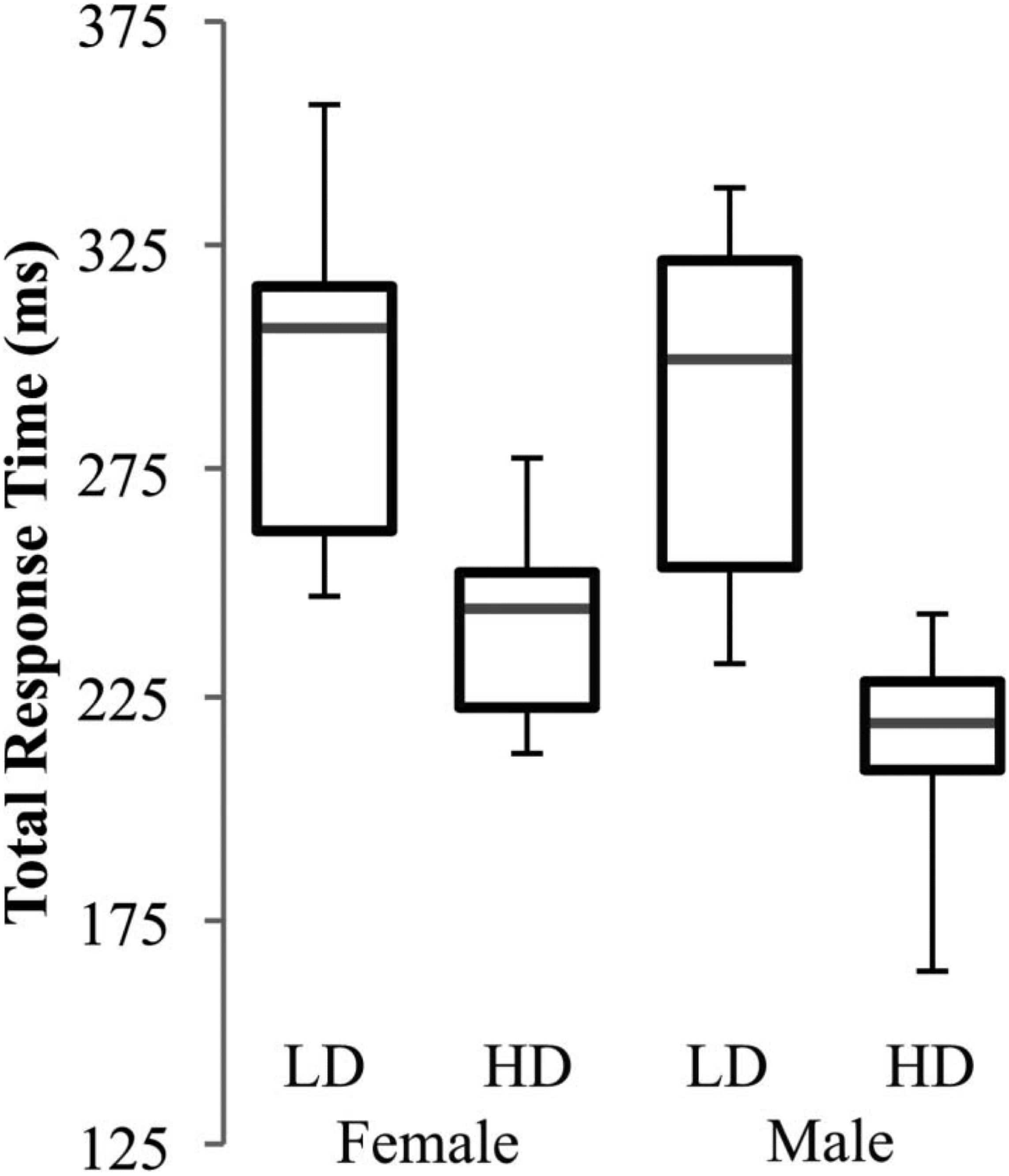

Figure 1.

Box plot of total response time by gender and task difficulty. Boxes represent quartiles, horizontal grey lines represent median values, and tails represent the maximum and minimum values. Abbreviations: LD – low task difficulty; HD – high task difficulty.

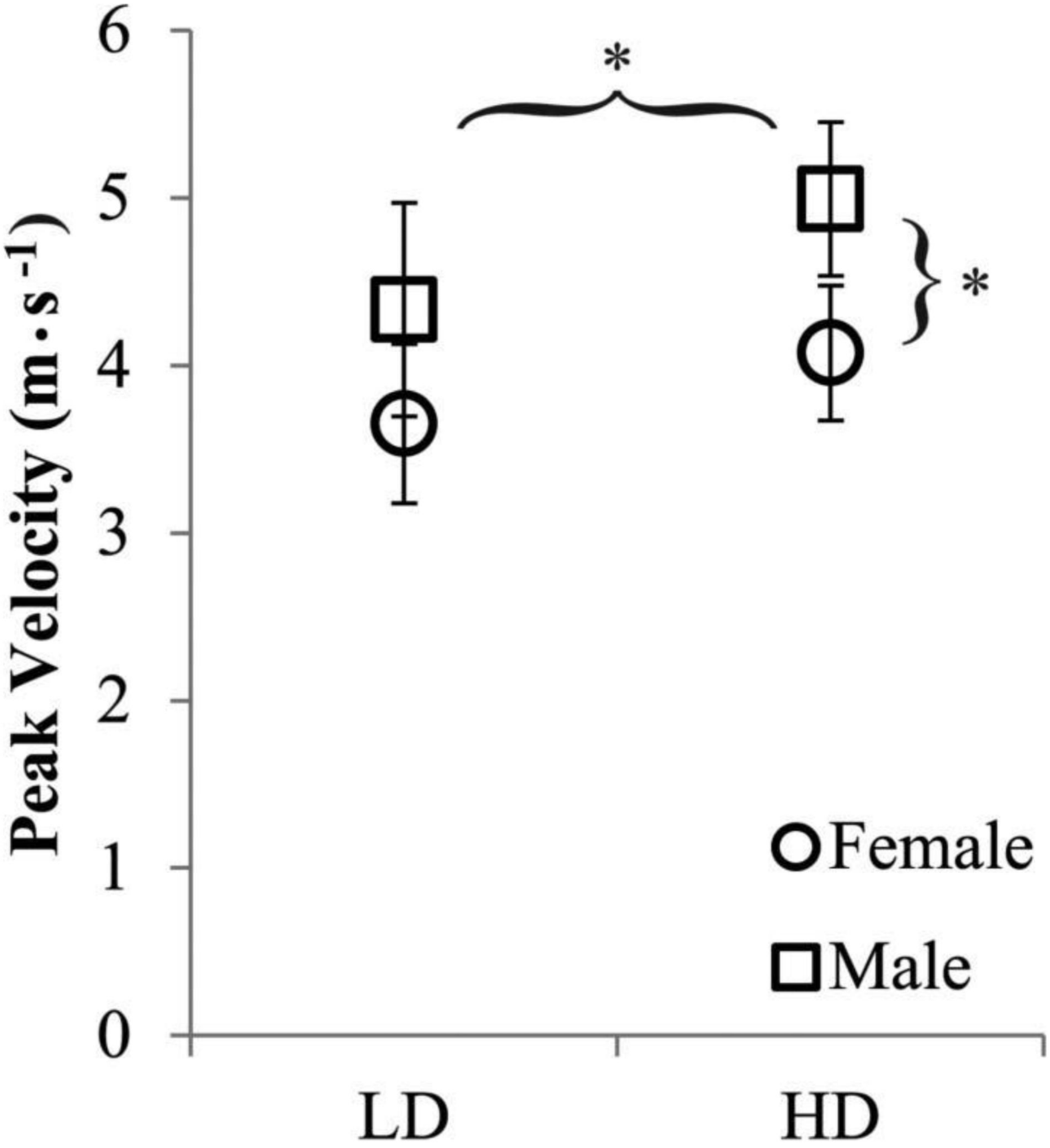

Figure 2.
Gender comparison of peak linear velocity in low difficulty (LD) and high difficulty (HD) testing conditions. Error bars indicate standard deviation for each measurement. * indiciates p-value < 0.001.

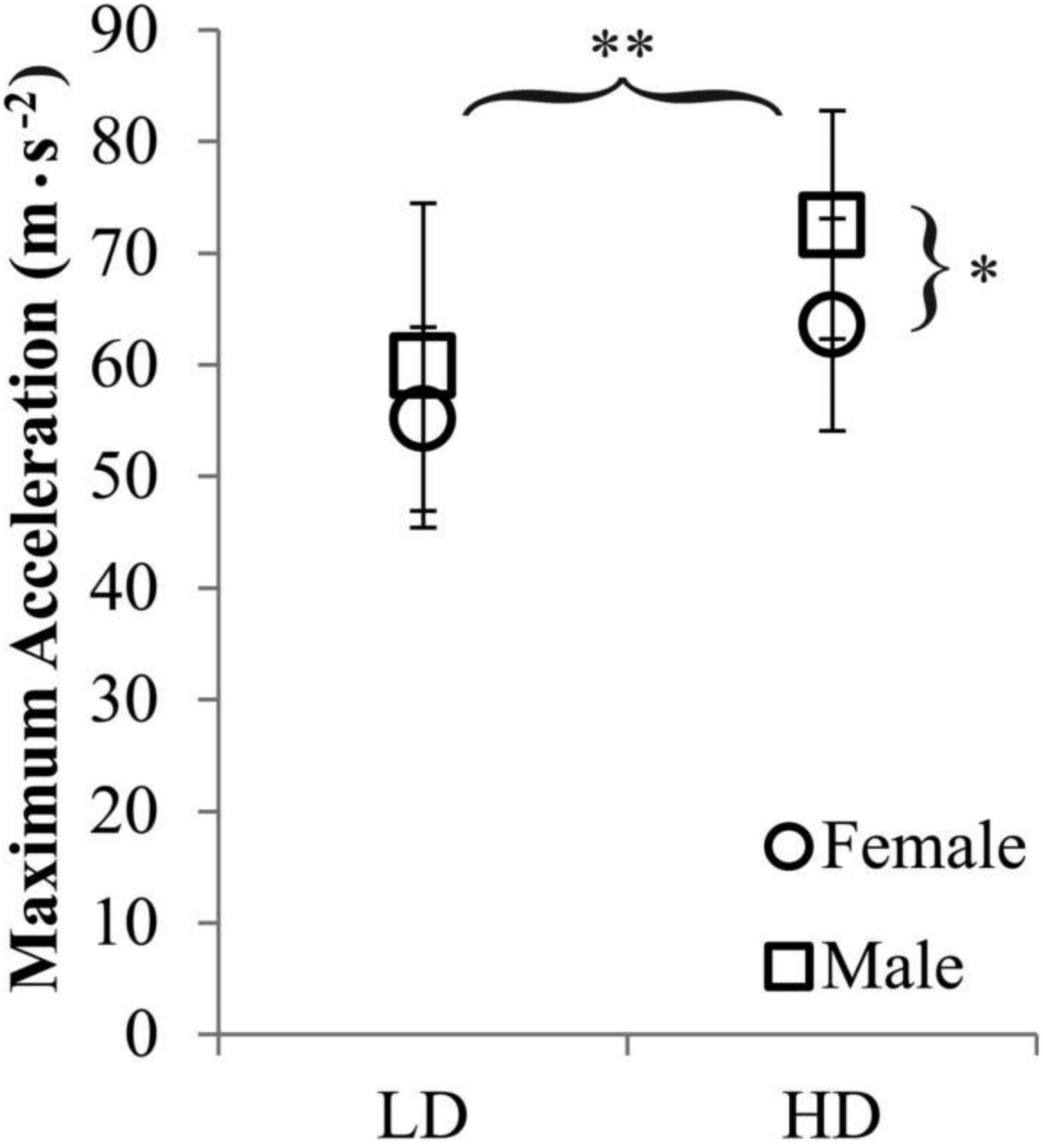

Figure 3.
Gender comparison of maximum linear acceleration in low difficulty (LD) and high difficulty (HD). Error bars indicate standard deviation for each measurement. * indicates p-value = 0.032 and ** indicates p-value = 0.001.

Table 1

. Effect of Gender and Task Difficulty on Reaction Time, Movement Time, and Total Response Time. (Times in ms)

	High Difficulty	Low Difficulty
Male		
Reaction Time	71 (15)[#]	105(19)
Movement Time	143 (19)[‡,#]	182 (26)
Total Response Time	214 (23) [*,#]	287 (39)
Female		
Reaction Time	79 (19)[#]	106 (13)
Movement Time	163 (18)[#]	189 (30)
Total Response Time	242 (22)[#]	295 (33)

Notes: Values are means (± 1 SD).

[*] Significant difference for gender ($p = 0.042$)

[‡] Trend towards significant difference for gender ($p = 0.054$)

[#] Significant difference for threat ($p < 0.001$)