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A Comparative Analysis of Softball Gloves:
Catcher's Glove Yields Highest Peak Hand Pressure

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

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A COMPARATIVE ANALYSIS OF SOFTBALL GLOVES: CATCHER’S GLOVE YIELDS HIGHEST PEAK HAND PRESSURE

(Thesis format: Integrated Article)

by

Brittany Hicks

Graduate Program in Kinesiology

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

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Abstract

Catchers commonly develop abnormal blood flow in the ulnar artery, digital ischemia in the index finger, and index finger hypertrophy as a result of continual trauma to the hand. The hand sustains peak pressures that are much greater than the recommended thresholds for repetitive tasks. The objective of this study was to measure the peak pressure on the hand when catching a softball and to determine which glove type (catcher’s glove, first baseman’s glove or fielder’s glove) is most effective at reducing the peak pressure on the hand. Pressure data was collected using Tekscan pressure sensors. Results indicate the hand sustains an average peak pressure of 232 kPa (first baseman’s glove), 269 kPa (catcher’s glove) and 191 kPa (fielder’s glove). The distal phalanx of the index finger most frequently sustains greater pressure than any other region of the hand. The fielder’s glove resulted in significantly lower peak pressures to the hand than the catcher’s glove (p=0.001). No other significant differences occurred between the three types of gloves. Modification to the glove design should be undertaken to minimize the risk of hand injury.

Keywords: Softball, baseball, gloves, catcher, fielder, first baseman, vascular injuries, blood flow, digital ischemia, pressure, peak pressure, pressure sensors
Co-Authorship Statement

Brittany Hicks was the first author, and Dr. Volker Nolte, Dr. Peter Lemon, and Dr. Jim Dickey are co-authors. All data in this thesis was collected, analyzed, and presented by Brittany Hicks.
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# Table of Contents

Abstract ................................................................................................................................. ii  
Co-Authorship Statement ..................................................................................................... iii  
Acknowledgments ................................................................................................................ iv  
Table of Contents ................................................................................................................ v  
List of Figures ....................................................................................................................... vii  
List of Appendices .............................................................................................................. x  
Chapter 1 .......................................................................................................................... 1  
1 General Introduction ....................................................................................................... 1  
Chapter 2 .......................................................................................................................... 2  
2 Literature Review .......................................................................................................... 2  
  2.1 Prevalence of Injury in Catchers ................................................................................. 2  
  2.2 Glove Design ............................................................................................................. 2  
  2.3 Vascular Injuries ....................................................................................................... 4  
  2.4 Abnormal Blood Flow ............................................................................................... 5  
  2.5 Digital Ischemia ......................................................................................................... 8  
  2.6 Pressure .................................................................................................................... 9  
    2.6.1 Pressure and blood flow .................................................................................... 10  
  2.7 Index Finger Hypertrophy ....................................................................................... 13  
  2.8 Preventing Injuries .................................................................................................. 13  
  2.9 Conclusion .............................................................................................................. 19  
  2.10 References ............................................................................................................ 20  
Chapter 3 .......................................................................................................................... 23  
3 Decreasing the Force of Impact: A Comparative Analysis of Softball Gloves .......... 23  
  3.1 Introduction .............................................................................................................. 23  
  3.2 Methods ................................................................................................................... 23  
    3.2.1 Participants ....................................................................................................... 23
List of Figures

Figure 1. The development of the catcher's glove .................................................................3
Figure 2. The catchable area using two hands to catch (left) and using one hand (gloved hand) to catch (right) ..................................................................................................................4
Figure 3. Anatomy of a fielder's glove .......................................................................................5
Figure 4. Ulnar canal and the surrounding structures in the wrist ..............................................7
Figure 5. Arterial anatomy of the hand .......................................................................................7
Figure 6. A Comparison of the pulsatile flow between index fingers ........................................8
Figure 7. A thermogram showing the colder areas (black areas) of the left index finger, hand, and forearm (left) ..................................................................................................................9
Figure 8. The average blood flow in the hand with different magnitudes of applied pressure .................................................................................................................................10
Figure 9. Blood flow in the skin of the index finger pad (top) and the applied pressure (bottom) .................................................................................................................................11
Figure 10. The approximate pain pressure threshold throughout the hand ...........................12
Figure 11. Tekscan F-Socket 9811 force sensors attached to the inside of the rugby pad .................................................................14
Figure 12. Force time profiles of two tackles with and without padding in rugby ......15
Figure 13. Distribution of the force at impact for three participants: (a)-(c) running tackles without padding; (d)-(f) running tackles with padding .................................................................16
Figure 14. Worth Century 33 inch catcher’s glove (A) and Worth Century 12.5 inch fastpitch first base mitt (B) .................................................................................................................................17
Figure 15. Pressure distribution of a bowling ball dropped onto four shock absorbing foam pads .................................................................................................................................18
Figure 16. Before and after compression of XRD® Technology and EVA foam ......19
Figure 17. Retained thickness of a variety of materials compressed at 55% for 22 hours .................................................................................................................................19
Figure 18. Orientation of the Tekscan Grip™ System pressure sensors on the hand24
Figure 19. Calibration of the Tekscan Grip™ System using an Instron® 8874 Axial-Torsion Fatigue Testing System .................................................................................................25
Figure 20. Cross section of the glove’s padding (left) and the padding held together by latex, which was used for the static calibration (right) .................................................................25
Figure 21. Set up for the study ..........................................................................................................................26
Figure 22. The process of editing frames: original recording (A), Frames cut to contact duration (B), Frames cut to impact (C) .........................................................................................28
Figure 23. Graphical representation of the peak hand pressures during the impact of the ball ........................................................................................................................................29
Figure 24. Calibration of the video using taped markings on the floor measuring one meter in length .................................................................................................................................30
Figure 25. The coordinate system origin (the bottom left corner of the screen) .........................31
Figure 26. A softball tracked during its flight ...............................................................................................31
Figure 27. Velocity of the ball over time .............................................................................................................32
Figure 28. Regions of the hand ..........................................................................................................................34
Figure 29. Percentage of peak contact pressure at each at each hand region for all glove types .........................................................................................................................................34
Figure 30. Percentage of peak contacts pressures at each at each hand region for each of the glove types ........................................................................................................................................35
Figure 31. An estimation of the distal phalanges and the second metacarpal head inside each of the gloves .......................................................................................................................................36
Figure 32. Average peak pressure sustained when using the three types of gloves. 37
Figure 33. Average peak pressures at the distal phalanx of the index finger, second metacarpal head and the distal phalanx of the thumb for the first baseman’s glove, the catcher’s glove, and the fielder’s glove ......................................................................................................................38
Figure 34. Two-dimensional representations of four different catches ranging from low to saturated pressures: low (top left), medium (top right), high (bottom left), and saturated (bottom right) ......................................................................................................................39
Figure 35. Pressure time curves for all trials using a first baseman’s glove .................................40
Figure 36. Pressure time curves for all trials using a catcher’s glove ..................................................40
Figure 37. Pressure-time curves for all trials using a fielder’s glove .................................................41
Figure 38. Comparison of the average pressure-time curves .................................................................41
Figure 39. Correlation between velocity (m/s) and pressure (kPa) when using a first baseman’s glove (A), catcher’s glove (B) and fielder’s glove (C)..............................43
Figure 40. The finger positioning and their corresponding finger sleeves (labelled 1-4) of a fielder’s glove with a finger shift design (model C125XT) .............................................46
Figure 41. Pressure-time curve for one softball catch.................................................................50
List of Appendices

Appendix: 1. Ethics Approval Notice from Western University Health Science Research Ethics Board

..........................................................56
Chapter 1

1 General Introduction

Baseball and softball are very similar sports. The key differences are that baseball pitchers throw a smaller ball (22.86 cm (9 in) circumference compared to a 30.48 cm (12 in) circumference of a softball), play on a bigger diamond, and pitchers throw over hand (compared to underhand windmill in softball). In addition, baseball pitchers throw 18.44 m (60 ft 6) in to home plate, while softball pitchers throw 13.1 m (43 ft).

Typically, baseball players experience vascular injuries to their gloved hand due to the repetitive impact of catching. Catchers have a significantly greater prevalence of vascular injury than players of any other position due to the increased number of impacts to the hand during games and practices (Ginn, Smith, and Snyder, 2005; Sugawara, Ogino, Minami, and Ishii, 1986). It should be possible to reduce injury severity, because the impact of the ball is expected and repetitive. Adjusting the catcher’s protective equipment may reduce the severity of an injury.

The current design of the catcher’s glove aims to provide a balance between protection and optimal performance. To improve the catcher’s grasping ability and control of the ball, padding was reduced in modern catching gloves (Rosciam, 2010). In addition, the modern catcher’s glove design causes the ball to be caught at the base of the webbing corresponding to the second metacarpal head, rather than impacting the glove further away from the palm (Ginn et al., 2005). Although additional padding in the glove might be used, some catchers are choosing to use a first baseman’s glove, which offers a larger pocket that is located further away from the palm of the hand.

The purpose of this study was to determine whether the first baseman’s glove, catcher’s glove, or fielder’s glove is more effective at decreasing the peak pressure on the hand. It was hypothesized that the first baseman’s glove will provide lower peak pressures to the hand than the catcher’s glove by moving the centre of pressure (base of the pocket) further away from the hand.
Chapter 2

2 Literature Review

2.1 Prevalence of Injury in Catchers

In softball, the most commonly injured regions of the body for all players are the hand and wrist (22.2%), with finger injuries accounting for 12.6% of all softball injuries (Birchak, Rochette, and Smith, 2013). Specifically, these injuries to the hand and wrist include mostly fractures and dislocations (40.2%), strains and sprains (26.5%), and soft tissue injuries (24.6%). Over half (52.4%) were caused by contact with the ball, not player-player collisions or player-bag collisions. Another study explored the injury rates in softball further and categorized the injuries by activity i.e. base running, hitting, and each of the nine positions (Marshall, Hamstra-Wright, Dick, Grove, & Agel, 2007). Their study discovered that catchers yielded the fourth greatest risk of injury in softball. The top four positions with the highest risk of injury accounted for 62.3% of total injuries: base runner (28.8%), batter (13.4%), pitcher (10.8%), and catcher (9.3%). More than 22% of all injuries sustained in games and practices prevented participation for at least 10 days. Of these serious injuries, fingers and hand fractures represented 12.8% (Marshall et al., 2007).

Moreover, catchers are more likely to have greater weakness and other hand symptoms like pain, numbness and tingling in their gloved hand compared to other players (44% versus 17%) (Ginn et al., 2005). When analyzing catchers alone, the gloved hand had a much greater prevalence of weakness (44%) and overall symptoms (56%), than the throwing hand (0% and 11%) (Ginn et al., 2005).

2.2 Glove Design

Although catchers do not experience the highest rates of injuries, their injuries are caused by repetitive impact, and, therefore, may be preventable. For example,
additional padding might disperse the forces more effectively and decrease the risk of injury.

As mentioned, the current design of the catcher’s glove favours dexterity over hand protection, because the amount of padding has decreased over time to improve grasping and allow greater control of the ball (Figure 1). This design aims to provide a balance between protection and optimal performance. Compared to catcher’s gloves today, gloves manufactured prior to the 1960s were constructed with a greater amount of padding (Ginn et al., 2005). However, the increased padding prevented the glove from fully closing, which is necessary to keep the ball in the pocket. To catch the ball, catchers had to use two hands to keep the ball in the glove. The need to use two hands to catch the ball decreases the catchable range and is, therefore, undesirable (Figure 2). The catchable range is limited to the radius where both hands can reach together. A single-handed catch has a greater catchable range because the arm can move through the full radius of arm movement (Figure 2).

Figure 2. The catchable area using two hands to catch (left) and using one hand (gloved hand) to catch (right). The total catchable area is greater when only using the gloved hand to catch the ball.

In an attempt to optimize performance, the padding in the glove was reduced, enabling catchers to catch the ball without the assistance of their throwing hand. When catching the ball with two hands, the catcher traps the ball in front before raising the ball to their shoulder to throw the ball. However, when catching the ball with one hand, the catcher can catch and transfer the ball to the throwing hand in one continuous motion. Transferring the ball in a continuous motion is much faster and, therefore, preferred. While the reduction in padding improved glove and ball control, as well as the speed of transfer between the glove and the throwing hand, it also reduced the protection to the gloved hand, exposing the catcher to an increased risk of injury.

2.3 Vascular Injuries

A common injury to baseball players is a vascular injury to their gloved hand (Nuber, McCarthy, Yao, Schafer, and Suker, 1990). These vascular injuries include abnormal blood flow and ischemia, which is a reduced blood supply to part of the body. Several studies have discovered that baseball catchers in particular have an increased prevalence of vascular trauma, when compared to players in other positions (Ginn et al., 2005; Sugawara et al., 1986). Catchers are at greater risk for hand injuries than
positional players due to the number of pitches that impact the catcher’s gloved hand. In addition to practice, they often catch close to one hundred high velocity pitches each game, with each pitch impacting the thumb and index finger, if they catch the ball in the pocket (Axe, Windley, and Snyder-Mackler, 2002).

The repetitive strain to the hand can cause vascular injuries, such as abnormal blood flow and digital ischemia (reduced blood flow to the fingers). Positional players usually catch the ball in the webbing of the glove (Figure 3), however, the modern design of the catcher’s glove causes catchers to catch the majority of balls at the base of the webbing, which corresponds to the second metacarpal head (Ginn et al., 2005). The nerves and digital vessels are vulnerable at the second metacarpal head where the ball is impacting the hand, which may explain the increase in vascular abnormalities in catchers. Due to the main impact of the ball on the index finger, the index finger is the most common digit to experience vascular abnormalities (Ginn et al., 2005; Pinkowsky et al., 2013).

Figure 3. Anatomy of a fielder's glove.

2.4 Abnormal Blood Flow

The vascular changes that catchers experience as a result of playing baseball have been studied by Ginn, Smith, and Snyder (2005). Digital vessel trauma, the damage to vessels in the fingers, is caused by the repetitive impact of the baseball on the hand. Their study participants consisted of thirty-six male baseball players. Of the thirty-six
players, nine were catchers, fifteen were pitchers, and twelve were positional players. Using a handheld Doppler ultrasound, the resting blood flow of the catchers' hands were compared to that of the positional players' hands. In an artery, normal blood flow produces three sounds per heart beat which is termed triphasic, while abnormal blood flow produces a fewer number of sounds, i.e. biphasic, uniphasic, or complete absent of any sound (Donnelly, Hinwood, and London, 2000). Using audio ultrasounds to detect the number of sounds, the functionality of the artery can be measured. This test identified one positional player and five catchers with abnormal blood flow in the gloved hand, of which two catchers had abnormalities in their throwing hand (Ginn et al., 2005).

The ulnar canal, located on the medial wrist, contains the ulnar artery and the ulnar nerve (Figure 4). The ulnar canal is formed by the hook of hamate (laterally) the pisiform (medially), and bound by the pisohamate ligament and flexor retinaculum (posteriorly), and by the palmar carpal ligament and palmaris brevis muscle (anteriorly) (Nuber et al., 1990). There are limited tissues to protect the ulnar artery as it exits the canal, making it extremely vulnerable to blunt trauma (Nuber et al., 1990). The ulnar artery and the radial artery are responsible solely for blood supply to the hand and fingers (Figure 5).

As mentioned, catchers have a statistically significant greater prevalence of abnormal blood flow in the ulnar artery at the ulnar canal of the gloved hand than other players, due to the repetitive impact involved in catching (Ginn et al., 2005). Analysis among catchers revealed a significantly greater prevalence of abnormalities at the ulnar canal in the gloved hand (four out of nine catchers) than in the throwing hand (zero out of nine catchers).

Figure 5. Arterial anatomy of the hand. Reprinted from "Arterial abnormalities of the hand in athletes" by G. W. Nuber W.J. McCarthy, J.S.T. Yao, M.F. Schafer, and
The prevalence of abnormal circulation in the catcher’s hand was supported by the study of Lowrey, Chadwick, and Waltman (1976), with the findings that 13 of the 22 catchers measured had abnormal circulation in the index finger of their left (gloved) hand, while only one out of 22 catchers had abnormal circulation in the index finger of their right (throwing) hand. The left index finger has reduced blood flow compared to the right index finger (Figure 6) (Sugawara et al., 1986).

Figure 6. A Comparison of the pulsatile flow between index fingers. The left index finger has reduced blood flow. Reprinted from "Digital ischemia in baseball players" by M. Sugawara, T. Ogino, A Minami, and S. Ishii, 1986, American Journal of Sports Medicine, 14, p. 331-332. Reprinted with permission.

2.5 Digital Ischemia

A questionnaire administered to baseball players suggested the prevalence of ischemia increases with the number of years played (Sugawara et al., 1986). Digital ischemia was found in 95 out of the 578 (16.4%) students who completed the questionnaire. Digital Ischemia occurred in 0% of the junior high school players, 22.1% of the high school players, and 87.9% of the college players. Further investigation of baseball players with digital ischemia symptoms (including numbness, coldness, and nail deformities), suggested that catchers and first basemen have a greater prevalence of
digital ischemia, because they catch the ball more frequently than the other players (Sugawara et al., 1986). Ischemia in catchers is thought to develop as a result of arterial occlusion and narrowing of digital arteries (Sugawara et al., 1986) (Figure 7).

Figure 7. A thermogram showing the colder areas (black areas) of the left index finger, hand, and forearm (left). The angiogram on the right showing the occlusion of the radial digital artery at the metacarpophalangeal joint (curved arrow, bottom right) and the occlusion of the ulnar digital artery at the proximal interphalangeal joint (thick arrow, middle right). Adapted from “Digital ischemia in baseball players” by M. Sugawara, T. Ogino, A Minami, and S. Ishii, 1986, American Journal of Sports Medicine, 14, p. 331-332. Reprinted with permission.

2.6 Pressure

Pressure is a measurement of the force per unit of area (Equation 1). Throughout the paper, pressure will be described in pascals (Equation 2).

\[
\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{N}{m^2} \quad (1)
\]

\[
1 \frac{N}{m^2} = 1 \frac{kg}{ms^2} = 1 \text{ Pa} \quad (2)
\]
2.6.1 Pressure and blood flow

Evidence suggests that pressures greater than the 98 kPa threshold will substantially occlude the blood flow in the skin of the hand (Johansson, Hägg, and Fischer, 2002). The average pressure required to reduce the blood flow in the skin by 50% is 21 kPa (index finger pad), and 24 kPa (thenar musculature), while the average pressure required to reduce the blood flow in the skin by 85% is 40 kPa (index finger pad) and 52 kPa (thenar musculature) (Figure 8) (Johansson et al., 2002).

Figure 8. The average blood flow in the hand with different magnitudes of applied pressure. Blood flow measurement recorded at the index finger pad (IF), middle phalanx of the middle finger (MF), palm (P) and thenar musculature (TM). Reprinted from “Skin blood flow in the human hand in relation to applied pressure” by L. Johansson, G. Hägg, & T. Fischer, 2002, European Journal of Applied Physiology, 86, p. 394-400. With Permission of Springer Science+Business Media.

After removing the external pressures on the index finger pad, an increase in blood flow to tissues (hyperaemia) was observed (Johansson et al., 2002). Rapid fluctuations in blood flow surround the pressure stimulus (Figure 9). The blood flow increased to 186%
in the index finger and 167% in the thenar musculature. Approximately, 2-5 minutes of rest was needed before the blood flow returned to normal (Johansson et al., 2002).

![Blood flow and pressure graph](image)


2.6.2 Pressure Discomfort Threshold

The discomfort threshold for the index finger pad is 188 kPa, while the discomfort threshold for the thumb is 100kPa (Johansson, Kjellberg, Kilbom, & Hagg, 2000). The discomfort pressure threshold was chosen when 50% of the subjects perceived the applied pressure to be uncomfortable. For a given pressure, subjects perceived the pressure to be more painful at the thenar musculature than at the palm or fingers.

2.6.3 Pain Pressure Threshold
The pain pressure threshold is much higher than the discomfort threshold. The average pain pressure threshold is 752 kPa (± 199) for the index finger, and 621 kPa (± 238) for the palm and thenar musculature (Johansson, et al., 2002). A catcher can withstand a greater amount of pressure applied to the index finger than the thumb, before perceiving the pressure as painful (Figure 10).

![Figure 10. The approximate pain pressure threshold throughout the hand. Reprinted from "Sensitivities of the hand to surface pressure" by C. Fransson-Hall and A. Kilbom, 1993, Applied Ergonomics, 24, p. 181-189. Reprinted with permission of Elsevier.]

2.6.4 Pressure Recommendations

Pain pressure thresholds for females are 50% lower than the pressure thresholds of males (Brennum, Kjeldsen, Jensen, and Jensen, 1989). It is recommended that tools exerting a pressure greater than 98 kPa (for females) and 196- 392 kPa (for males) should be avoided to reduce the risk of injury (Lindstrom, 1973 quoted in Fraser, 1980). Although the use of tools and catching are quite different, the repetitive use of tools can
be applied to the repetitive nature of catching. The pressure threshold for repetitive use (98 kPa) corresponds to approximately 20% of the female pain pressure threshold.

Vascular injuries may develop without the subject's realization, because the blood flow in the skin occludes at a much lower pressure than is required to feel pain. Continual occlusion of the blood flow in the skin may explain the vascular symptoms observed in catchers.

2.7 Index Finger Hypertrophy

As a result of catching, additional abnormalities in the glove hand can be observed (Ginn et al., 2005). Seven of the nine catchers studied showed signs of index finger hypertrophy in their gloved hand but not in their throwing hand. In all cases, the soft tissue surrounding the proximal phalanx and the interphalangeal joint of the index finger was enlarged. Hypertrophy of the index finger of the gloved hand is very common for experienced catchers, as another study found that all twenty-two catchers studied experienced it (Lowrey et al., 1976).

Index finger hypertrophy “was found to occur exclusively in catchers”, indicating a highly significant difference between the gloved hand of catchers and positional players (Ginn et al., 2005). By comparing the sizes of the catchers’ index fingers using a jeweller’s ring sizer, the gloved hand index finger was found to be on average 1.89 ring sizes larger than their throwing hand index finger. Although, the presence of index hypertrophy is not in itself harmful, its presence is symptomatic evidence of the body’s response to stress.

2.8 Preventing Injuries

It is important to reduce the pressure exerted on the hand when catching in order to reduce the risk of abnormal vascular development. Modifying the glove to more effectively reduce the peak pressure applied to the hand may reduce the risk of injury.

2.8.1 Additional Padding
Catchers are statistically more likely to use additional padding than any other position (p<0.01) (Ginn et al., 2005). The use of additional padding is necessary to protect against repetitive trauma, as catchers using additional padding have a lower prevalence of vascular injury (Lowrey et al., 1976). All nine of the 22 catchers with normal circulation used additional padding (a thick golf glove, handball glove or even a sponge), suggesting padding may have a protective effect on hand circulation.

Another study, measured the effectiveness of rugby pads in reducing peak impact forces of rugby tackles (Pain, Tsui, and Cove, 2008). Results indicate that padding can reduce the average peak impact force by 40% (p=0.086). Each of the six male participants rotated between tackling (both lower and higher velocities) and being tackled. Tackles were performed with and without the additional padding. The use of padding reduced the average peak impact force of high velocity tackles by 41% (p=0.0017). The impact forces were measured using Tekscan F-Socket 9811 force sensors secured to the inside of rugby pads (Figure 11). For tackles without padding, the force sensors were secured to a customized vest worn by the subject to stabilize the sensor’s position.


The force sensors are composed of numerous sensels (sensing elements), which measure either the contact pressure or the contact force during impact (Tekscan, n.d.).
The magnitude of pressure is dependent on the area upon which the forces are acting. Padding can reduce pressure effectively by dispersing the forces over a larger area.

Peak force was measured for tackles with and without protective padding, revealing that there was a 40% reduction in peak force at impact for tackles using padding compared to those without padding (Figure 12). The total force at the moment of impact can be mapped to display the distribution across the sensors (Figure 13).

![Graph showing force time profiles of two tackles with and without padding in rugby.](image)

Tackles while wearing shoulder pads resulted in a lower peak force and greater contact area (Figure 13). However, this study provided no evidence that dispersing the forces will reduce the severity of injury (Pain et al., 2008). To determine the effect of padding on prevalence of injury accurately, a controlled longitudinal epidemiological study needs to be performed.

2.8.2 First Baseman’s Glove

Many catchers report that they avoid using additional padding because they fear it will diminish their ‘feel for the ball’ (Nuber et al., 1990). The pocket of the first baseman’s glove is further from the index distal phalanx than a catcher’s glove, which may reduce the peak forces on the hand without decreasing the player’s performance due to their similar design (Figure 14). Consequently, using a first baseman’s glove may prove to be a good alternative to the catcher’s glove. Further, the transition to a first baseman’s
glove may be an easy solution, because many catchers are already using the first baseman’s glove. Further, there is some anecdotal support as Team Canada Softball Catchers and a Boston Red Sox Catcher, Victor Martinez prefer the first baseman’s glove, claiming the larger pocket improves their performance (Kaplan, 2010).

Figure 14. Worth Century 33 inch catcher’s glove (A) and Worth Century 12.5 inch fastpitch first base mitt (B). Both gloves are for right throwing players. Adapted from “Gloves” (n.d.). In Worth Fastpitch. Retrieved from http://shop.worthsports.com/Products/fpgloves. Reprinted with permission.

2.8.3 Quality of Padding

Glove manufacturers have tested different types of padding in order to optimize force distribution. For example, Rawlings, one manufacturer of baseball and softball gloves, manufactures some gloves using a type of padding called XRD® Technology, while other gloves are made with EVA foam. XRD Technology appears to be more effective at absorbing the impact (XRD, n.d.). The testing of several types of foam pads suggests that XRD Technology reduces the peak pressure at impact (Figure 15). For each type of padding, a weight was dropped onto a pressure sensor with the padding on top (XRD,
The XRD Technology was more successful in reducing peak pressures by more effectively dispersing the forces.


Additionally, XRD Technology padding is more resistant to damage from compressive forces than EVA foam (Figure 16). XRD Technology uses an open cell structure while EVA foam uses a closed cell structure. After compression, the material returns to its original form, while EVA foam remains partially compressed. Through compression, padding can absorb and distribute the applied forces. However, if the padding cells burst, the cells cannot return to their original state (remains partially compressed) and the padding will be less effective at dispersing additional forces. XRD Technology is far more superior in maintaining thickness than the padding alternatives (Figure 17).


2.9 Conclusion

Catchers are prone to long-term hand injuries caused by the repetitive impacts of catching balls. The catcher is at an increased risk of developing vascular injuries, particularly in the index finger. Although catching gloves are able to distribute some of
the forces to the entire hand, the high prevalence of vascular injuries suggests that catching gloves do not protect the hand adequately from repetitive trauma (Ginn et al., 2005). In order to reduce the risk of vascular injuries, altering the design of the catcher’s glove or using additional padding should be considered.

Improving the design of the catcher’s glove might be the best approach to reduce the pressures applied to the hand below 98 kPa because many players avoid using additional padding. The first baseman’s glove may reduce peak pressure, as it maintains optimal performance while shifting the centre of pressure further away from the hand. However, future studies are needed to determine which style of glove is most effective in reducing the peak pressures applied to the hand.

2.10 References


Chapter 3

3 Decreasing the Force of Impact: A Comparative Analysis of Softball Gloves

3.1 Introduction

Baseball catchers frequently develop vascular injuries due to the repetitive impact of the ball to the gloved hand (Ginn, Smith, and Snyder, 2005; Sugawara, Ogino, Minami, and Ishii, 1986). Adjusting the glove to more effectively reduce the peak pressures to the hand may minimize the risk of developing these vascular injuries. The purpose of the present study was to determine whether the first baseman’s glove, the catcher’s glove, or the fielder’s glove is most effective at decreasing the peak pressure on the hand. Pressures acting on the distal phalanx of the first, second and third digits as well as the second metacarpal head were isolated for glove comparison. The thumb and index finger surround the pocket of the glove, and are more susceptible to injury than digits 3-5 (Ginn, Smith, and Synder, 2005; Lowrey, Chadwick, and Waltman, 1976; Pinkowsky, Roberts, Allred, Pujalte, and Gallo, 2013).

3.2 Methods

3.2.1 Participants

The study was conducted using eight subjects from the Western University women’s Softball Team. One subject was excluded from the study due to problems with the data collection. Only seven subjects were included in data analysis (n=7). Each subject satisfied the following inclusion criteria: female, aged 18-25, throw right-handed, with experience playing on a university softball team. Experience in the catching position was not a requirement for participation.

3.2.2 Equipment

Tekscan 4256E pressure sensors (Tekscan, model/ map 4256E) were used to measure the pressure on the hand while catching a softball. The Tekscan pressure sensor is
composed of 18 different sensing regions (including a total of 349 sensels), which were taped over the proximal, intermediate, and distal phalanges, metacarpal heads (digits 2-5), and the thenar and hypothenar musculature using 3M™ Transpore™ Surgical Tape (Figure 18).


A static calibration of the Tekscan Grip™ System (sensor model 4256E) was performed (Figure 19). Using an Instron® 8874 Axial-Torsion Fatigue Testing System, known forces were applied uniformly across the sensing area of the sensor. Between the sensor and the applied force, a cross section of a first baseman’s glove wrapped in latex was positioned to mimic the materials used during the study (Figure 20). Two calibration points (90N and 180N) were entered into the CONFORMat® software, creating a two-point calibration curve. The calibration was performed using only the sensor region located on the palm below the thumb (Refer to Figure 18 c). All data collection and calibration information were recorded using mid sensor sensitivity.
3.2.3 Set Up

The Tekscan Grip™ System was taped to the participants' hands to ensure the sensors were recording impact to only the designated area of the hand consistently. The tape completely covered the entire sensing area of each sensor to prevent a ridge, which can cause an area of high pressure. A latex glove was worn over top of the sensors to
provide further adherence. On top of the sensors and latex glove, the subjects wore each of the three types of softball gloves.

Strict guidelines were used to set up the equipment in the gymnasium before the arrival of each participant (Figure 21). A line on the gymnasium floor was used as a guideline for the path of the ball. At one end of the line (13m away) a pitching machine (Jugs Jr.™ Pitching Machine) was placed and at the other end of the line two perpendicular lines were placed, providing a one-metre long reference scale for video analysis. A net was placed behind the catcher to contain any balls that passed by the catcher. Two high-speed cameras (capturing at a rate of 210 frames per second) where placed for later video analysis. The first camera was positioned directly behind the pitching machine and aimed at the catcher to capture the catcher’s movement in the frontal plane and the location of the impact of the ball on the glove. The second camera was placed perpendicular to the catcher to capture the catcher’s movement in the sagittal plane and the movement of the ball for calculation of its velocity. Additional lighting was placed beside the perpendicular camera to improve video capture.

![Diagram of set up](image)

**Figure 21. Set up for the study.**

The pitching machine was used to maintain a relatively consistent speed of the ball throughout each of the trials. The pitching machine was set to the maximum setting, approximately 60 mph (26.8 m/s).

Three different types of gloves were tested from the Worth Century series: catcher’s glove (model CCMX), first baseman’s glove (model CFBMX), and fielder’s glove (model
C125XT). All gloves were supplied by Rawlings Canada. All three types of gloves are manufactured using Poron® XRD padding. No methods were taken to 'break in' the gloves, however all three gloves were tied around a ball to provide a slight shape to the pocket, increasing the catcher’s ability to close the glove around the ball. All three gloves were tied for the same length of time (approximately one week).

Prior to testing the three gloves, the catcher was given one practice trial (using a practice glove used only for the practice trials). The practice trial was used to familiarize the subject with the set-up, as well as the speed and trajectory of the ball. After one practice trial, the subject switched gloves catching 10 pitches with each of the three types of gloves (a total of 30 pitches were caught). Throughout the study, each subject used the same three gloves. The total number of impacts to each glove remained the same across all glove types to control glove stiffness. The order of gloves used was randomized for each participant to remove any bias in trainability.

3.2.4 Converting To Qualified Data

All sensor recordings were captured using the Tekscan CONFORMat® software. The recordings were later analyzed using the Tekscan I-Scan® software. To ensure all pressure data reflected only the contact of the ball with the glove, all recordings were edited to exclude any over activated or saturated sensels (damaged or crinkled sensors) before ball contact. These sensels were removed from all frames to prevent an overestimation of pressure caused by sensor damage. The recordings were then cut down to focus only on the duration of impact (Figure 22). The period of impact was distinguished as the brief spike in pressure (less than one second) while the increased pressure following the impact (lasting several seconds) was excluded. The longer lasting pressure corresponds with the fingers applying pressure to the glove in order to keep the ball in the pocket.
Figure 22. The process of editing frames: original recording (A), Frames cut to contact duration (B), Frames cut to impact (C).

Using the Tekscan I-Scan® software, pressure data were separated by various regions of the hand. For each trial, pressure data for five regions were chosen: the entire hand, the distal phalanx of the index finger and middle finger, the second metacarpal head, and the distal phalanx of the thumb (Figure 23). For each region, the peak contact pressure over the duration of the impact of the ball was exported to Microsoft® Excel. The maximum pressure value was selected for each region and compiled for all trials.
Figure 23. Graphical representation of the peak hand pressures during the impact of the ball. The object boxes are shown in yellow, green, red, blue and purple boxes with their corresponding peak pressures (kPa).

3.2.5 Excluding Trials

To measure the pressure the hand sustained, all fingers must be in the glove when catching a ball. One participant caught the ball with their index finger outside of the glove. This technique is common, however this technique did not allow for collection of the balls impact to the index finger. The participant was removed from the study, because the index finger is of particular focus in the study.

Over the seven included participants (210 trials), 173 trials were included in the study (37 trials excluded). Trials where the sensing region was damaged (an absence of pressure recordings for the index finger) were excluded.
3.2.6 Calculating Ball Velocity

A stationary high-speed camera was positioned perpendicular to the flight of the ball. Using Kinovea, a video analysis software, the position of the ball was tracked over the course of the flight as the ball entered the field of view until it approached the glove. A calibration was performed for all trials using the tape markings on the floor of the testing location. Calibration from the left side of the left hash mark to the left side of the right hash mark was set to one meter (Figure 24).

![Figure 24. Calibration of the video using taped markings on the floor measuring one meter in length.](image)

For all videos, the bottom left corner of the video was selected as the origin for coordinates (Figure 25). This location ensures the location of the ball has a positive coordinate over the course of its flight. The centre of the ball was marked in each frame and is connected to create the trajectory of the ball (pink line) (Figure 26).
Figure 25. The coordinate system origin (the bottom left corner of the screen).

Figure 26. A softball tracked during its flight.

The coordinates of the ball in each frame were exported to Microsoft® Excel in centimeters (for increased precision), which were later converted into metres. By setting the first position of the ball as zero, the displacement of the ball was calculated. The resultant displacement was obtained from the horizontal and vertical displacement (Equation 3). The time between frames is assumed to be a constant 1/210 s.

$$\text{Resultant displacement } (r) = \sqrt{X^2 + Y^2}$$  \hspace{1cm} (3)
Due to minor digitization errors or pixel limitations, minor errors occur in tracking the centre of the ball. When converting position into velocity, these errors are amplified (Equation 4). To minimize the effects of these errors, a velocity time graph with an exponential trendline was created for each flight (Figure 27). Any outliers in the final position of the ball were eliminated to prevent skewing the trendline. By selecting the time of the final position of the ball as X in the trendline equation, a more accurate estimation of the final velocity was calculated.

![Graph showing velocity over time with an exponential trendline equation: \( y = 23.479e^{0.1677x} \)]

**Figure 27. Velocity of the ball over time.**

### 3.2.7 Time between Pitches

A Western University softball game was analyzed to determine the frequency and the length of time between catches. Using a video analysis software (Kinovea), each catch by one team’s catcher was time stamped and exported to Microsoft Excel. Over the course of the game, the average time between catches and the standard deviation were calculated.
3.2.8 Statistical Methods

Using the average peak pressure for each subject, a one-way analysis of variance was performed to measure the effect of glove type on peak pressure. A two-way analysis of variance was used to compare the average peak pressures at the four isolated regions of the hand (second metacarpal head, and distal phalanx of the thumb, index finger and middle finger) for each of the three gloves (First baseman`s glove, Catcher`s glove, and Fielder`s glove). The Levene`stest identified equal homogeneity of variances between the three glove types, but identified unequal homogeneity of variances between the four isolated regions of the hand. A Tukey`stest analysis for equal variances was performed to identify in which gloves the significant difference occurred, while a Games-Howell post hoc test for unequal variances was performed to identify in which hand region a significant difference occurred.

3.3 Results

The study consisted of a ball impacting three different styles of gloves with the approximate speed of 24.08 m/s (±1.79). No difference was found between the first baseman`shand, the catcher`shand, and the fielder`shand (p=0.408). The distal phalanx of the index finger sustained the greatest peak pressures on the hand. The distal phalanx of the index finger sustained significantly higher peak pressures than the distal phalanx of the thumb (p<0.001). The pressures recorded up to a maximum of 380 kPa.

3.3.1 Location of Impact

The regions of the hand are determined by the location of the sensors` placement (Figure 28). The subjects most often experienced peak pressures at the distal phalanx of the index finger (Figure 29). The distal phalanx of the middle finger and the second metacarpal head are the next most prevalent regions of the hand to sustain peak pressures.
Figure 28. Regions of the hand.

Figure 29. Percentage of peak contact pressure at each hand region for all glove types. A total of 173 trials conducted. The regions of the hand are illustrated in Figure 28.
Contact pressure on each region of the hand is further differentiated by glove type (Figure 30). For all three gloves, the distal phalanx of the index finger (region 3) most frequently sustained the highest pressure on the hand. However, the remaining locations showed different occurrences of peak pressure for each glove type. Using one subject, a general location of the distal phalanges and the second metacarpal head inside each glove are depicted for comparison (Figure 31). For each glove the distal phalanx of the index finger was the closest part of the hand to the base of the pocket. The distal phalanx of the index finger was approximately 50% further from the base of the pocket in first baseman’s glove and the fielder’s glove when compared to the catcher’s glove.

Figure 30. Percentage of peak contacts pressures at each at each hand region for each of the glove types. The regions of the hand are illustrated in Figure 25.
Figure 31. An estimation of the distal phalanges and the second metacarpal head inside each of the gloves. Catcher’s glove (top), first baseman’s glove (middle), and fielder’s glove (bottom).
3.3.2 Magnitude of Pressure

The hand sustains an average pressure of 232 kPa (first baseman’s glove), 269 kPa (catcher’s glove), and 191 kPa (Fielder’s glove) (Figure 32). There was no effect of glove type on the peak pressure sustained (p=0.408).

![Bar chart showing average peak pressure sustained by glove type]

**Figure 32. Average peak pressure sustained when using the three types of gloves. Error bars represent the standard deviations.**

The maximum pressure the sensors could record was 380 kPa. The sensors recorded the maximum more often when using the catcher’s glove (32%) and the first baseman’s glove (30%), than compared to the fielder’s glove (14%).

There was a significant effect of hand region on peak pressure sustained (p=0.001). When comparing the average peak pressure of each glove at the distal phalanx of the index finger and middle finger, the second metacarpal head and the distal phalanx of the thumb, a significant difference occurred only between the distal phalanx of the index finger and the distal phalanx of the thumb (p=0.001) (Figure 33). At the distal phalanx of the index finger, second metacarpal head, the distal phalanx of the thumb, and at the distal phalanx of the middle finger, no significant differences occurred between gloves, indicating no interaction between glove type and location (p>0.05).
Figure 33. Average peak pressures at the distal phalanx of the index finger, second metacarpal head and the distal phalanx of the thumb for the first baseman's glove, the catcher's glove, and the fielder's glove. Error bars represent the standard deviations. A * denotes significant differences between regions of the hand.

A two dimensional representation demonstrates the range in pressure detected during the study (Figure 34). The force time curves of all included trials are represented below (Figures 35-37). The average force time curves (shown in bold) are compared for the three glove types (Figure 38).
Figure 34. Two-dimensional representations of four different catches ranging from low to saturated pressures: low (top left), medium (top right), high (bottom left), and saturated (bottom right).
Figure 35. Pressure time curves for all trials using a first baseman’s glove. The average pressure-time curve is represented in bold (black dashed line).

Figure 36. Pressure time curves for all trials using a catcher’s glove. The average pressure-time curve is represented in bold (black dashed line).
Figure 37. Pressure-time curves for all trials using a fielder's glove. The average pressure-time curve is represented in bold (black dashed line).

Figure 38. Comparison of the average pressure-time curves.
3.3.3 Effect of Velocity

The velocity of the ball fluctuated between trials. The average velocity for all trials was 24.08 m/s (± 1.79). To measure the effect of the velocity of the ball on hand peak pressure, a correlation was performed (Figure 39). For each glove, a weak positive correlation was found between velocity and pressure ($r^2 = 0.103$, $r^2 = 0.086$, and $r^2 = 0.032$).

![Graph A](image)

![Graph B](image)
Figure 39. Correlation between velocity (m/s) and pressure (kPa) when using a first baseman’s glove (A), catcher’s glove (B) and fielder’s glove (C) (r= 0.322, r= 0.293, and r= 0.180).

3.3.4 Catch Frequency

A supplementary study analyzed game footage of one university game. Video analysis of the entire Canadian Collegiate Softball Association National Championship game, computed an average interval between catches of 33.09 seconds (± 29.47s). Only one team’s catcher was analyzed in the video. The interval only includes the time between the catches in live play, and does not include warm up pitches or the time between the last catch in the inning and the first catch in the subsequent inning.

3.4 Discussion

3.4.1 Pressure

Although the long-term symptoms of softball catchers are not well documented, baseball catchers develop serious vascular injuries, as noted in Chapter 2. Improving softball gloves to better distribute forces and reduce the peak pressures exerted to the hand may reduce the risk of these injuries.
The average pressure applied to the hand for all gloves in this study was 232 kPa. When using the catcher’s glove, subjects sustained the highest peak pressures on the hand (average 269 kPa of all trials), compared to the first baseman’s glove (232 kPa of all trials), and fielder’s glove (191 kPa of all trials).

It is assumed that at this pressure level, the blood flow in the index finger pad is occluded, because applying 40kPa to the distal phalanx of the index finger occluded the blood flow 85% (Johansson et al., 2002). This pressure likely causes blood flow occlusion and the ensuing hyperaemia (an increased blood flow to tissues) (Johansson et al., 2002). The average pressure applied to the index finger while catching with any of the three gloves for all trials is 134 kPa. This pressure greatly exceeds the recommended pressure threshold for repetitive tasks of 98 kPa (Lindstrom, 1973 quoted in Fraser, 1980).

Unfortunately, the microvascular blood flow occludes at a much lower pressure than required to feel pain or discomfort. Although the pressure exerted to the hand when catching likely does not exceed the pain pressure limit (approximately 500 kPa for women), the catcher may feel discomfort when the pressure exceeds the discomfort pressure limit (approximately 100 -188kPa depending on the region of the hand). Both the average peak pressure applied to the index finger (134 kPa) and thumb (45 kPa) do not exceed the suggested discomfort threshold (188 kPa and 100 kPa). Without the sensation of discomfort, the catcher may not fully understand the consequences for continual impacts above the recommended threshold. Therefore, reducing the peak pressure the hand sustains when catching a softball must become a priority when designing gloves.

The pressure applied to the hand can be reduced by: increasing the surface area at which the force is applied (by dispersing the forces through padding), or by reducing the force applied. Through conservation of momentum, the force of the ball is transferred to the glove: \( \Delta M = m \Delta V = F \Delta t \). To reduce the force applied to the glove, the time of impact must increase. Modifying the catcher’s technique (negative movement of the glove) or through the use of more compressive padding, the impact time can be increased.
3.4.2 Hand Location in the Glove

Many digits sustained peak pressures over the course of the study; however, the primary concern of this study was to compare the top four regions of the hand that most frequently receive peak pressures: the distal phalanx of the index finger, distal phalanx of the middle finger, second metacarpal head and the distal phalanx of the thumb.

Analysis of baseball catchers suggests the second metacarpal head aligns with the base of the glove pocket (Ginn et al., 2005). However, during the present study it was observed that the base of the pocket did not align with the second metacarpal head but instead aligned more closely to the distal phalanx of the index finger (Figure 31). The differences between a baseball glove and a softball glove may account for the discrepancy.

Pressure data collected during the study indicates the distal phalanx of the index finger most frequently sustains the highest levels of pressure (39%), while the second metacarpal head and distal phalanx of the middle finger are further away from the base of the pocket, and thus sustains lower levels of pressure (16% and 17%). The increased pressure acting on the distal phalanx of the index supports the observation by Ginn et al. (2005) that the ball impacts the base of the pocket primarily during the catch. The high prevalence of vascular injuries to the index finger is supported by the frequency of peak pressures applied to the index finger. Evidence suggests that gloves should reduce the peak pressure the hand sustains more effectively, with particular focus to the index finger. A combination of finger proximity to the pocket and padding quality may affect the pressure sustained.

Of the four most frequent impact locations on the hand, the thumb sustained the lowest peak pressure despite its close proximity to the pocket. In all three gloves, the padding overlying the thumb is much thicker than the padding over the fingers, which may explain the reduction in pressure.

Additionally, the fielder’s glove tested in the study used a different hand positioning than the standard positioning. The standard position is putting each digit in a separate finger
sleeve. However, the glove tested used a finger shift design. Rather than placing the index finger (second digit) in the first finger sleeve of the glove (next to the pocket), the glove was designed to place the index finger (second digit) into the second finger sleeve of the glove (Figure 40). The middle finger (digit 3) is placed in the third finger sleeve, leaving both the ring and little finger (digits 4-5) to go in the fourth finger sleeve.

![Figure 40](image)

**Figure 40.** The finger positioning and their corresponding finger sleeves (labelled 1-4) of a fielder's glove with a finger shift design (model C125XT).

Using a finger shift design moves the distal phalanx of the index finger further from the impact location of the ball (base of the pocket) than what would be expected in a standard fielder's glove. Positioning the index finger further away from the pocket, explains at least partially the lower peak pressures applied to the distal phalanx of the index finger. Modifying the catcher's glove and first baseman's glove to shift the fingers further from the pocket (where the majority of pitches are caught), will likely decrease peak pressures to the index finger.

### 3.4.3 Game Application

Previous studies only investigated injuries of baseball catchers, rather than softball catchers. These studies certainly can provide a general understanding to catcher injuries, however they may apply poorly to softball catchers because of many key
differences between the sports (ball size, glove differences, and velocity of the ball). A softball is 12 inches in circumference compared to 9 inches for a baseball. Catching a larger ball may explain the greater radius of impact surrounding the pocket of the glove than was expected. The high pressures acting on the distal phalanx of the thumb and the distal phalanx of the middle finger are thought to occur for this reason. The larger ball size may not only cause vascular injuries to the index finger (as suggested by literature), but also to the surrounding digits. Further research is needed to evaluate the prevalence of injury in softball catchers.

The current study measured the pressure applied to the hand by a softball projected at a moderate velocity (24 m/s). During elite games and practices, competitive catchers would be required to catch softballs up to 34 m/s, a 42% increase in velocity (New Speed, 2012). Although a weak correlation exists between pressure and velocity ($r^2 = 0.103$, $r^2 = 0.086$, and $r^2 = 0.032$), the range in velocity was small. With a small range in velocity, technique may play a larger role in the amount of pressure the hand sustains.

A ball with a greater velocity will have a greater momentum. To catch a ball with a greater velocity without increasing the peak pressure applied to the hand, the catcher must catch the ball in a more optimal location on the glove (not overlying the hand) or the catcher must increase the time of impact. The catcher may only be able to provide a limited amount of negative motion to reduce the pressure on the hand. Increasing the range of velocity may reveal a greater correlation between velocity and pressure. The pressure applied to the hand in the current study exceeds the recommended threshold of 98kPa. In a game where the velocity of the ball is much greater, the pressures may be even greater, increasing the risk of injury.

Using video analysis of a university softball game, the time between catches was calculated. Over the course of the game, the Western University catcher caught a ball on average every 33.09 seconds ($\pm 29.47$s). The time between catches depends primarily on the effectiveness of the pitcher and the hitter. Of course, this pitch frequency should only be considered as a rough estimation because only one game
was used. A more extensive video analysis should be conducted to better estimate the catch frequency.

Regardless, the time between pitches is likely insufficient time for the blood flow in the hand to return to normal (Johansson, Hägg, and Fischer, 2002). Following the removal of an external pressure, hyperaemia occurs, increasing the blood flow to the tissues (Johansson et al., 2002). It takes approximately 2-5 minutes before the blood flow in the skin returns to normal. It is unlikely that the catcher has sufficient time between pitches for the circulation in the finger to return to normal. The repetitive occlusion of the index finger’s blood flow without sufficient rest time, may explain the observed vascular injuries to the catchers’ index fingers.

A larger analysis of the 2014 Major League Baseball season, revealed the average time between pitches to be 18.29 seconds (Lindbergh, 2014). The time between pitches in softball is likely similar, as softball pitchers are required to pitch the ball within 20 seconds of receiving the ball (Softball Canada, 2013). It is reasonable to assume that most catchers do not have two minutes between catches to facilitate blood flow normalization. Therefore, reducing the peak pressures applied to the hand is essential in reducing the risk of injury.

3.4.4 Limitations

One limitation of this study is the small sample size. With only seven subjects, the statistical power of the study, and the ability to detect a significant effect, is reduced.

Further, only one glove manufacturer was tested. Different manufacturers have slight variations in the design and in the materials of their gloves. The pressure differences between the three gloves may not remain consistent when considering models from a variety of manufacturers.

Additionally, the Tekscan pressure sensors used were fragile and did not maintain structural integrity over the course of the study. Many Tekscan Grip™ System sensors were used throughout the study. Many trials were excluded due to sensel damage. The index finger in particular was prone to sensel damage (nonresponsive). Additionally, the
sensors were prone to wrinkling during recording, causing sensels to overestimate the pressure applied to the hand. All trials were reviewed to eliminate overactive sensels by deleting high pressure sensels before the point of impact.

The Tekscan Grip™ System can record at varying sensitivities. The sensitivity is important to consider, as there is a trade-off between resolution and range when changing the sensitivity. A lower sensitivity increases the range of pressures detected, however, the ability to differentiate between similar pressures decreases. Alternatively, a higher sensitivity decreases the range of pressure, but allows a greater ability to distinguish between two pressures.

A middle sensitivity setting was chosen to record the pressure for its balance between resolution and range. It was important to be able to compare similar pressures between gloves, as well as provide a sufficient range. By selecting a middle sensitivity, a maximum pressure of 380 kPa was selected. Although the pressure sensors may not have recorded the true peak pressure in many catches (maxing the sensors at 380 kPa), this maximum is well beyond the recommended pressure threshold for repetitive activities. Future studies should measure catches using a lower sensitivity to capture the true peak.

Although the study only considered the impact of the ball, the peak pressures may have been over-estimated by including any pressures caused by voluntary contraction. Following the impact of the ball (the initial spike in pressure), a pressure curve lasting several seconds occurred (Figure 41). The pressure sustained lasts much longer than the expected impact of the ball, and is attributed to pressure exerted by the voluntarily contraction of the thumb to close the glove, trapping the ball in the pocket. However, in some trials it was difficult to determine where the impact curve ended and the voluntary contraction began. In such trials, an overestimation of the peak pressure acting on the thumb may have occurred.
Figure 41. Pressure-time curve for one softball catch.

The lack of a correlation between velocity and pressure ($r^2 = 0.103$, $r^2 = 0.086$, and $r^2 = 0.032$) suggests that the location of the impact of the ball or the catcher’s technique affects the pressure exerted on the hand. These factors could not be controlled for during the study.

With the use of a pitching machine to control the velocity and trajectory of a ball, the majority of the balls were predictable with the same spin. However in a game, there are many different pitches: predominantly drop balls, rise balls, change ups and curve balls. Each pitch creates a different spin causing a different trajectory. The catcher must not only predict the end position of the ball, but must ‘frame’ the ball to the umpire. Framing the ball is catching a ball that is near or outside the strike zone and making it appear within the strike zone using slight movements at the wrist. Sometimes this results in catching the ball outside of the pocket. The glove’s ability to disperse the forces may change when catching the ball in a non-optimal location. Future studies should be conducted in a more game-like scenario (live pitching with a variety of pitches) to improve the generalizability of the study.

3.5 Summary/Conclusion

With the high prevalence of vascular injuries to the catcher’s gloved hand, glove manufacturers must find a balance between hand protection and performance. At
present, glove selection is driven by performance rather than protection so small modifications may be the likely course of action.

Glove companies have modified their gloves to reduce peak pressures by using more efficient padding (XRD® Technology) and shifting the fingers further away from the pocket. However, the hand continues to sustain pressure beyond the recommended threshold. As the discomfort pressure threshold is much greater than the recommended threshold, catchers may not be aware of the severity of impact. Glove design must continue to change to reduce the risk of vascular injuries.

No significant effect was found between glove type and peak pressure sustained (p=0.408). Although, the hand sustained the lowest peak pressures when using the fielder’s glove, its improved protection may depend upon the catcher using the finger shift placement in the glove. Using a finger shift placement inside the glove may further reduce the peak pressures to the hand when catching with a first baseman’s glove or a catcher’s glove.

Contrary to pre-conceptions, the first baseman’s glove may prove to be a superior choice for catchers. The first baseman’s glove optimizes performance with its bigger pocket and longer reach, while lowering the peak pressures. Although, the difference between the peak pressure while using the first baseman’s glove and the catcher’s glove is not significant, the hand sustains a lower peak pressure when using the first baseman’s glove. It can be assumed that safety will not be compromised when switching from a catcher’s glove to a first baseman’s glove, as the hand sustained similar peak pressures when using both gloves.

A more extensive study, measuring gloves from multiple manufacturers and comparing the finger shift placement versus the standard placement is needed before making a conclusive recommendation.
3.6 References


Chapter 4

References


Appendix

Appendix: 1. Ethics Approval Notice from Western University Health Science Research Ethics Board
Curriculum Vitae

Name: Brittany Hicks

Post-secondary Education and Degrees:

Western University
London, Ontario, Canada

McMaster University
Hamilton, Ontario, Canada
2009-2013 B.Sc. Kin.

Awards:
Western University, Faculty of Health Sciences
Travel Award (2015)

Western University, Kinesiology
Travel Award (2015)

Memberships:
Canadian Society for Biomechanics

Presentations:
Ontario Biomechanics Conference
Oral presentation

Western University Research Day
Poster Presentation

Related Work Experience:
Teaching Assistant
Western University
2013-2015