Comparison of Glove Specifications, 3D Hand Scans, and Sizing of Sports Gloves for Female Athletes

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Abstract

Gloves are used in many sports as a form of protective gear and to enhance performance. Inadequately fit gloves can be detrimental to an athlete's ability to perform. As the population of female athletes grows and diversifies, it is important to ensure glove fit and performance across the plethora of sports. Despite improvements in the availability of anthropometric data, measurements of the hand remain limited. In recent years, 3D scanning has improved to capture complexities of the hand. 3D scan data of the hand offers potential to improve the sizing, fit and design of gloves for sports.

There is a need to better understand anthropometric hand data in relation to female athletes and sports activities to improve future glove fit standards and performance. The purpose of this study was to collect, compare, and analyze 3D hand scans (30 subjects) versus actual glove specifications and sizing of commonly used sports gloves. A close fitting golf glove (FootJoy Women's StaSof) was selected for comparison. Scans were taken of each subject's dominant hand (landmarked in 30 locations for accuracy) with the Occiptial Structure Sensor and iPad, and measured with Anthroscan software. Detailed specifications of the gloves that related to measurements of the hand were recorded and compared to the population measurements to determine how well the selected glove model fit each subject. To better serve diverse users, results suggest that traditional glove sizing is inadequate and more anthropometric data of the hand are needed to inform better glove sizing and fit. Based upon the findings of this study, future studies will be conducted to evaluate various glove brands and activities.

Keywords: Athletic gloves, sports, sizing, 3D scanning, anthropometric measures, fit

1. Introduction

Gloves are used in many sports as a form of protective gear and to enhance performance. Inadequately fit gloves can be detrimental to an athlete's ability to perform. As the population of female athletes grows and diversifies, it's important to ensure glove fit and performance across the plethora of sports. Close fitting gloves are used in numerous sports ranging from golf to softball. Glove design and fit are traditionally created using limited anthropometric data. Despite improvements in the availability of anthropometric data, measurements of the hand remain limited. In recent years, 3D scanning has improved to capture complexities of the hand. 3D scan data of the hand offers potential to improve the sizing, fit and design of gloves for sports.

There is a need to better understand anthropometric hand data in relation to female athletes and sports activities in order to improve future glove fit standards and performance. For this research, golf and golf gloves were selected to examine the relationship between female hand anthropometry and glove specifications. This pilot study will explore state-of-the-art leather golf glove sizing, specifications across a size range, along with how well 3D female hand scans size and fit into a leading U.S. brand.

2. Background

2.1. Women in Golf and Definition of golf sports gloves

The modern sport of golf has origins in 15th Century Scotland, and continues to attract players world-wide with skill sets ranging from hobby to professional. Today, the percentage of women playing golf is around 24% and the percentage of women entering the sport is increasing every year [1].

Gloves are worn by players to improve grip on the golf club as a player swings (figure 1). A golf glove can provide a tackier grip, more friction on the club, and can prevent the club from turning in a player's hand. Gloves are traditionally worn on one hand, however, some players wear them on both hands.

Leather golf gloves covering the hand and wrist are the most common glove, however gloves with synthetic materials or a combination of materials are increasing their market share. Because of the nature of how golf gloves are used, a next-to-skin fit is ideal. Incorrect fit, such as any extra material in the fingers and/or palm region, can have detrimental effects on a player's game.

Fig. 1. Image of hands grasping club with golf gloves [2]

2.2. 3D Anthropometric hand data of women

Glove fit challenges exist because there is a lack of accurate and relevant anthropometric data for designers [3]. This is especially true for women, as the majority of anthropometric data collected in the U.S. is from military personnel, includes limited measures (e.g., hand circumference, breadth, and Length), and is only in a 2D format. To develop better performing products for the hand, the researchers are interested in building a more accessible 3D women's hand scan database and improving the relationship of the 3D scan data to product design. To date, the researchers have investigated methodology to collecting 3D hand scan data, 3D hand scan technology assessment, hand proportions as it relates to designing gloves from a sketch, dynamic hand scanning and a performance glove design process [4-12].

3. Experimental Procedures

Having gloves that properly fit women is imperative to comfort and athletic performance. The relationship of the measurements of the hand and the measurements of a glove are a key factor in providing good fit to the wearer. The purpose of this research was to pilot a method to collect, compare, and analyze 3D hand scans of women to the specifications of a commonly sold leather golf glove purchased in the U.S.

3.1. 3D Hand scanning method

A convenience sample of thirty women were recruited from the University of Minnesota and the University of Oregon. Prior to scanning, subjects reviewed and signed a consent form approved by the Institutional Review Board of the partnering institutions. Each subject's dominant hand was landmarked using washable marker and vinyl circular stickers at twenty-six locations. The landmark locations are based on the procedure outlined by Griffin, Kim, Carufel, Sokolowski, Lee, and Seifert [6].

Next, the subject's hand was 3D scanned in a splayed position using an Occipital Structure Sensor attached to an Apple iPad. The splayed hand position was selected based on ISO 7250-1:2017 method for collecting anthropometric measurements and the ease of measurement comparison between the selected glove and the 3D scan [13]. A frame with clear plexiglass was used to stabilize the hand during the scanning process which took approximately one-minute per scan. Figure 2 shows the scanning process using the Occipital Structure Sensor and an example of the resulting scans. The scans with color and texture were saved as .OBJ files, cleaned and oriented in the AnthroScan software.

Fig. 2. 3D hand scanning process with Occipital Structure sensor

3.2. Glove selection and justification

The two leading golf equipment companies are Acushnet, who own Titleist and FootJoy, and Callaway [14]. In 2018, FootJoy sold $439.68 million in gear, Callaway sold 329.89 million, and Titleist 146.07 million [14]. Based on this data, FootJoy is likely to have the largest market share in gloves, followed by Callaway and Titleist.

The glove selected for this study was the FootJoy Women's StaSof golf glove. This traditional women's golf glove is constructed from an exclusive leather from Pittards of England that is designed to optimize and retain softness and flexibility [15]. The glove design features a negative cut with Keystone thumb, secure closure on the back of the hand, elastic on the back of the hand and wrist, and strategically placed perforation to improve breathability and flexibility. A negative cut in gloves is a style of cut that has finger gussets between the palm and backhand, which allows the fingers to be held in place and produces an overall snugger fit. A keystone thumb style features a set-in thumb piece and is known for comfort and improved dexterity in glove design.

The FootJoy StaSof glove comes in four women's sizes: Small (LS), Medium (LM), Medium-Large (LML), and Large (LL). This model of glove was selected because FootJoy has the largest glove marketshare, they market multiple sizes for women, the product is available to women at retail and online, and the glove has extensive size selection procedures provided by the manufacturer.

Fig. 3. FootJoy StaSof Leather Womens Golf gloves

3.3. Measurement definitions

Once the 3D scans were obtained and the gloves selected, measurements were defined to enable an accurate comparison between the two. Traditionally, anthropometric measurements and product measurements vary greatly, and it is not possible to do a direct comparison between manufacturer specifications and an anthropometric database. The value of 3D scans is that they enable researchers to take an infinite number of measurements that are product specific. For this study, the researchers

defined fourteen measurements that are critical to glove fit that included a range of finger and hand lengths, widths, and circumferences. The palm circumference measurements were defined based on common anthropometric measurements and the manufacturer defined method for size selection. Figure 4 provides a diagram of the comparative hand and glove measurement locations. Table 1 provides definitions and locations of each hand and glove measurement and delineates the measurement type (surface or linear).

Fig. 4. Measurement points for hand and gloves

Table 1. Comparative hand and glove measurement definitions and locations.

Hand Measure #	Measurement Definition	Glove Measure #	Measurement Definition
1H	Length measure from the distal tip of 5th finger to wrist crease. Measure follows along the side of the hand. Surface measure.	1G	Length measure from the distal tip of glove's 5th finger to the glove's wrist. Measure follows along the side of the glove. Surface measure.
2H	Length measure from the distal tip of 5th finger to the interdigital fold. Measure is centralized through the finger. Linear measure.	2G	Length measure from the distal tip of glove's 5th finger to the lower finger crotch. Measure is centralized through the finger. Linear measure.
3H	Length measure from the distal tip of 4th finger to the interdigital fold. Measure is centralized through the finger. Linear measure.	3G	Length measure from the distal tip of glove's 4th finger to the lower finger crotch. Measure is centralized through the finger. Linear measure.
4H	Length measure from the distal tip of 3rd finger to the interdigital fold. Measure is centralized through the finger. Linear measure.	4G	Length measure from the distal tip of glove's 3rd finger to the lower finger crotch. Measure is centralized through the finger. Linear measure.
5H	Length measure from the distal tip of 2nd finger to the interdigital fold. Measure is centralized through the finger. Linear measure.	5G	Length measure from the distal tip of glove's 2nd finger to the lower finger crotch. Measure is centralized through the finger. Linear measure.
6H	Length measure from the distal tip of 1st finger to the interdigital fold. Measure is centralized through the finger. Linear measure.	6G	Length measure from the distal tip of glove's 1st finger to the crotch. Measure runs parallel to the fold of the thumb pattern. Linear measure.

7H	Length measure from the distal tip of 1st finger to wrist crease. Measure follows along the side of the hand. Surface measure.	7G	Length measure from the distal tip of glove's 1st finger to the glove's wrist. Measure follows along the side of the glove. Surface measure.
8H	Circumferential measure at the 2nd to 5th finger interdigital folds. Surface measure.	8G	Circumferential measure around the glove's 2nd to 4th lower finger crotches. Surface measure.
9H	Circumferential measure at the bottom of the 1st finger interdigital fold parallel to 8H or 12H. Surface measure.	9G	Circumferential measure at the top of the 1st finger glove's crotch parallel to the wrist. Surface measure.
10H	Length measure from the 3rd finger interdigital fold to the wrist. Measure is centralized through the 3rd metacarpal. Linear measure.	10G	Length measure from the glove's 3rd finger crotch to the glove's wrist. Measure is squared through the backhand of the glove. Linear measure.
11H	Length measure from the distal tip of 3rd finger to the wrist. Measure is centralized through the 3rd metacarpal. Linear measure.	11G	Length measure from the distal tip of glove's 3rd finger to the glove's wrist. Measure is squared to the backhand of the glove. Linear measure.
12H	Circumference measure of the smallest part of the wrist. Surface measure.	12G	Circumference measure of the smallest part of the glove's wrist. Surface measure.
13H	Length measure from the distal tip of 2nd finger to the interdigital fold. Surface measure.	13G	Length measure from the distal tip of the glove's 2nd finger to the center of the glove's 1st finger crotch. Surface measure.
14H	Length measure from the distal tip of 2nd to distal tip of 1st finger. Surface measure.	14G	Length measure from the glove's distal tip of 2nd to distal tip of the glove's 1st finger. Surface measure.

3.4. Hand and glove measurements

Once the measurements were defined for both the hand and the glove, the 3D scans and gloves were measured in centimeters using standard measurement tools. For all 3D scans, AnthroScan software from Human Solutions was used to extract measurements. First, landmarks were visually located on the 3D scans and a digital landmark was placed in the software program to create an accurate guide for measurements.

For glove measurements, product landmarks were placed using a permanent pen on the interior, and measurements were collected manually three times with a flexible, plastic tape measure. The measurements were averaged and documented in a spreadsheet.

3.5. Size Selection

Prior to analyzing measurements, ease assumptions were created for the glove to hand comparison. As there are no formal guidelines for incorporating ease values into gloves, ease assumptions were derived by the authors based on the assumptions of the glove use and fit. Because the glove is meant to be worn "next-to-skin" and excess material can hinder the athlete's performance, the researchers concluded that no ease should be incorporated into the hand measurement values.

Using the size selection process provided online by FootJoy, the measurements 4H (length of the distal tip of the 3rd finger) and an additional circumference measurement at the knuckles were used to segment the subjects into the appropriate size category. A tape measure and a diagram were provided by the company online [15] to assist in finding the correct size (figure 4). The diagram uses a numerical code for each measurement of 0-9. Table 2 shows the FootJoy numerical code and the corresponding measurement used to compare the middle finger (4H) and the circumference of the hand. The subjects' measurements were translated into the FootJoy numerical code, and a size was selected based on the diagram in figure 5.
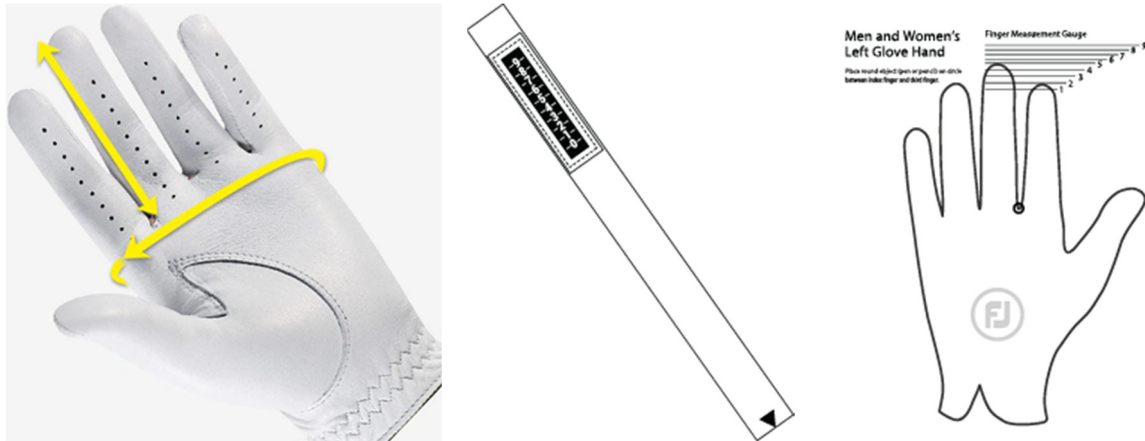
Fig. 4. FootJoy gloves size selection process

Table 2. FootJoy gloves size selection: Measurements of the hand compared to FootJoy numerical code for middle finger length and circumference of hand.

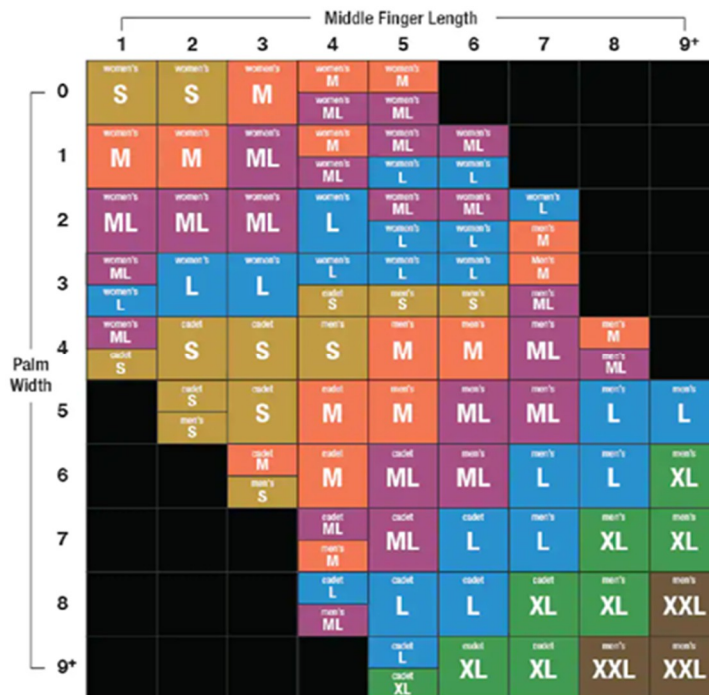| FootJoy Size Selection	Middle Finger Length: 4H	Circumference of hand around first knuckle (excluding thumb): 8H
0	-	18.9
1	7	19.5
2	7.4	20.1
3	7.8	20.7
4	8.2	21.3
5	8.5	21.9
6	8.8	22.5
7	9	23.1
8	9.3	23.7
9	9.6	24.3

Fig. 5. FootJoy gloves size selection process

4. Results

4.1. Subjects

3D hand scans from a convenience sample of thirty women, aged 18-65 years, from Oregon and Minnesota were collected for this study. Twenty-nine scans were useable.

4.2. Hand anthropometric measurements

Basic statistics were performed on the measurements on the subject data acquired from the 3D hand scans. For each of the fourteen measurements described in Table 3, the maximum (MAX), minimum (MIN), average, standard deviation, and range were calculated for the sample. Table 3 presents those measures.

Table 3. Hand anthropometric measurements (in centimeters).

	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H
MAX	15.51	7.64	9.09	9.65	9.29	7.10	14.00	23.86	23.39	11.90	21.18	18.19	12.44	20.51
MIN	11.80	4.80	5.70	6.90	6.40	4.57	9.40	18.60	18.20	9.20	16.80	14.50	7.20	13.58
Average	13.76	5.90	7.24	7.99	7.22	5.89	11.60	20.95	20.11	10.78	18.70	16.22	10.43	16.43
Standard Deviation	1.00	0.66	0.79	0.63	0.68	0.53	1.11	1.22	1.08	0.70	1.13	1.04	1.07	1.31
Range	3.71	2.84	3.39	2.75	2.89	2.53	4.60	5.26	5.19	2.70	4.38	3.69	5.24	6.93

The sample used for this study had a broad range of hand sizes and variances. 6H, a linear measurement of the distal tip of the 1st finger to the interdigital fold, represented the smallest range and standard deviation of the sample, 2.53cm and .53cm respectively. 14H, a surface measurement from the distal tip of the 2nd digit through the web-space to the distal tip of the 1st finger, represented the largest range and standard deviation of the sample, 6.93cm and 1.31cm respectively.

4.3. Glove specification measurements

From specification data acquired from the size small (LS), medium (LM), medium-large (LML) and large (LL) leather golf gloves, averages were calculated for each of the fourteen identified measures. Table 4 presents those measures. Overall, the specifications for these gloves showed good linearity across each measurement between the sizes. This indicates that the manufacturing for these particular gloves is precise.

Table 4. Glove specification measurements (in centimeters).

	1G	2G	3G	4G	5G	6G	7G	8G	9G	10G	11G	12G	13G	14G
LS Glove	15.03	6.5	8.26	8.4	7.7	5.2	13.2	19.6	20.73	9.53	17.8	15.23	11.06	17.76
LM Glove	16.06	6.6	8.43	8.8	7.83	5.56	13.16	19.7	19.06	10	18.56	15.1	11.4	17.96
LML Glove	16.33	6.9	8.63	9.05	8.23	6.13	13.76	20.93	19.76	10	18.96	16.46	12.16	18.86
LL Glove	16.86	7.3	8.96	9.23	8.5	6.2	14.96	20.76	19	10.03	19.4	15.96	11.83	19.6

4.4. Size distribution based on glove fit system

An analysis was conducted to understand how well the sample when divided into Small, Medium, Medium-Large, and Large sizes (based to FootJoy's size selection guide) fits into the women's glove models measured for the study. The size selection chart and directions (fig. 4, Table 2, and fig. 5) were used as a basis for analysis. Size distribution of the sample is found in figure 6.
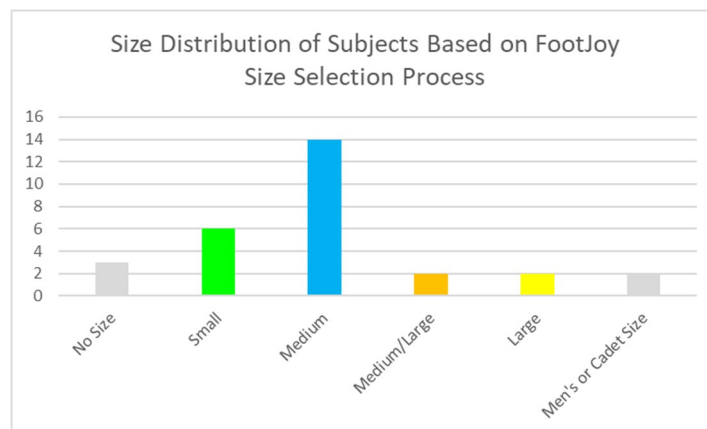

Fig. 6. Size distribution based on FootJoy size selection process

Overall, nearly 83% of the sample fit into a women's specific glove. Twenty-four subjects fit into the women's FootJoy size system, with 2 subjects fitting in a Men's or Cadet Size and 3 subjects with no size recommendation. The women's medium size fit the most subjects (n=14), followed by small (n=6), medium/large (2), and large (n=2).

4.5. Hand anthropometric measures vs. glove specification measures

Once the hand scans were assigned glove sizes, the researchers were able to compare the glove specifications to the 3D hand scan anthropometric measurements. Table 5 shows the results of the averaged glove specification measures compared to the average hand anthropometric measurements, for both sizes. The percentage of difference was calculated for each of the measures between glove specifications and the hand. If the resulting number was positive – then the glove was larger than the hand measure. If the resulting measure was negative, then the glove was smaller than the hand (too tight). In cases where the measurement was negative, it was highlighted in red in Table 5 as the consumer would not be able to properly fit into the glove. If the glove was more than +15% different than the hand, it was highlighted in grey.

Table 5. Glove specification measures vs. hand anthropometric measurement data
for Small, Medium, Medium-Large, and Large sizes (in centimeters).

	1G/H	2 G/H	3G/H	4G/H	5G/H	6G/H	7G/H	8G/H	9G/H	10G/H	11G/H	12G/H	13G/H	14G/H
SMALL GLOVE	15.03	6.5	8.26	8.4	7.7	5.2	13.2	19.6	20.73	9.53	17.8	15.23	11.06	17.76
SMALL SUBJECTS N=6	13.07	5.23	6.49	7.27	6.65	5.87	11.11	18.12	19.49	10.58	17.72	15.66	10.19	15.96
% Difference	15.01%	24.30%	27.23%	15.59%	15.70%	-11.41%	18.80%	8.19%	6.38%	-9.97%	0.44%	-2.74%	8.49%	11.26%
MEDIUM GLOVE	16.06	6.6	8.43	8.8	7.83	5.56	13.16	19.7	19.06	10	18.56	15.1	11.4	17.96
MEDIUM SUBJECTS N=14	13.46	6.02	7.35	7.99	7.23	5.77	11.32	18.70	20.04	10.63	18.62	16.07	10.41	16.46
% Difference	19.28%	9.67%	14.75%	10.10%	8.36%	-3.66%	16.29%	5.35%	-4.87%	-5.92%	-0.34%	-6.05%	9.48%	9.12%
MEDIUM-LARGE GLOVE	16.33	6.90	8.63	9.05	8.23	6.13	13.76	20.93	19.76	10.00	18.96	16.46	12.16	18.86
MEDIUM-LARGE SUBJECTS N=2	15.15	5.65	7.15	8.45	7.60	6.70	13.30	19.85	21.05	11.40	19.65	16.55	10.55	16.50
% Difference	7.79%	22.12%	20.70%	7.10%	8.29%	-8.51%	3.46%	5.44%	-6.13%	-12.28%	-3.51%	-0.54%	15.26%	14.30%
LARGE GLOVE	16.86	7.3	8.96	9.23	8.5	6.2	14.96	20.76	19	10.03	19.4	15.96	11.83	19.6
LARGE SUBJECTS N=2	13.85	5.45	6.60	7.85	6.70	5.35	12.10	20.60	20.10	10.85	18.60	16.90	9.85	15.25
% Difference	21.73%	33.94%	35.76%	17.58%	26.87%	15.89%	23.64%	0.78%	-5.47%	-7.56%	4.30%	-5.56%	20.10%	28.52%

Results clearly show that glove specifications and hand anthropometric data are not aligned. Across all sizes, there are measurements that have a significant negative and positive percent difference between the glove and hand. This indicates that the proportion of the glove to hand is incorrect.

For the Small size comparison, measurements 6G/H, 10G/H, and 12G/H were all too small for the subjects, with measurement 6G/H being -11.41% too small. Measurements 1G/H, 2G/H, 3G/H, 4G/H, 7G/H, and 14G/H were all over +10% between the hand and glove, meaning that the glove was over 10% larger than the hand sample measurements.

When comparing measurements for 1G/H, 2/GH, 3G/H, 4G/H, 5G/H, 7G/H, 8G/H, 12G/H, 13G/H, and 14G/H, the Medium glove would be too large for the sample, up to +19.28%. Whereas, when comparing measurements for 6G/H, 9G/H, 10G/H, 11G/H, and 12G/H, the Medium glove would be too small for the sample, up to -5.92%.

When comparing the Medium-Large glove, 1G/H, 2G/H, 4G/H, 5G/H, 7G/H, 8G/H, 13G/H, and 14G/H measurements were all too large for the sample subjects, up to +22.12%. Measurements 6G/H, 9G/H, 10G/H, 11G/H, and 12G/H were all too small for the sample, up to -12.28%.

For the Large glove, measurements 1G/H, 2G/H, 2G/H, 4G/H, 5G/H, 6G/H, 7G/H, 11G/H, 13G/H, and 14G/H were all too large compared to the hand, up to +35.76%.

This golf glove style is meant to provide a snug, next-to-skin fit so no ease was incorporated into the hand measurements for the comparison. Even if a 2-5% ease value was added to the hand measurements, there would still be a significant measurement difference between the glove and hand.

5. Discussion and conclusion

Results from this pilot study uncovered significant areas for improvement in terms of the glove to hand measurement relationship. Comparing product specifications to the actual sample demonstrated a clear need to improve the fit of the gloves for consumers, specifically the relationship between hand measurements and product specifications. Finger and palm length, as well as web-space areas offer significant opportunity for improvement. There is also a need for developing industry-wide ease standards. Standards should be based upon material thickness, flexibility, stretch, and glove functionality. Ease values should also be validated through wear testing.

This pilot study demonstrates one method of utilizing the data from 3D hand scan through comparing product specifications to hand measurements. Beyond product specific measurements, there is a need to develop new ways to apply 3D hand data to the design development of gloves and other products for the hand. Based upon the findings of this study, future research will be conducted to evaluate a larger sample of women, various glove brands/styles, and activities (e.g., firefighting, medical surgery and other sport).

6. Acknowledgements

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