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Skin deformation behavior during hand movements and their impact on functional sports glove design

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Abstract

In this study a three-dimensional (3D) INFOOT scanner was used to scan the hand in different postures and Geomagic Studio 12 was used to measure and analyzes the skin deformation behavior (skin relaxed-strain ratio) during various sport activities. Thirteen female participants between the ages of 40-65 years with hand size medium (M) performed a relaxed hand posture and two dynamic postures which were relevant to key sport activities. There were significant differences in the skin relaxed-strain ratio between the experimental postures, especially in phalangeal and metacarpal regions with exception in (third finger-metacarpal region). The results of this study suggest that the metacarpal region had significantly larger skin relaxed-strain ratio than the phalangeal region and metacarpal-carpal region. This study has contributed to enhancing the knowledge of the skin deformation behavior during various sports activities which could be incorporated into sports and functional glove pattern design and engineering for improving the fit, comfort, and functionality of a sport glove.

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1. Introduction

Functional sporting gloves are commonly used and required in numerous sports such as hockey, baseball, lacrosse golf and cycling. The role of sports gloves is primarily functional, such as providing wearers with protection from impact and abrasion, or enhancing performance by allowing greater grip or dexterity. In spite of their protective and enhancing purpose, the gloves should not restrict the wearer's hand function such as grip and

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dexterity. Design factors such as the fit of a glove should enable dynamic freedom of movement while avoiding undesired pressure that could impede the grip strength; range of motion; performance of task; and physiological comfort of users [1].

The effects of gloves on hand performance have been investigated by number of researchers and many suggest that poorly designed or fitted gloves are likely to reduce hand dexterity, tactile sensitivity, hand strength and increase hand fatigue [2, 3]. The performance of the gloved hands is substantially affected by the properties of the glove's material and most importantly by the fit of the gloves [4]. Gompers [5], stated that a functional glove that does not fit or is uncomfortable to wear is a glove that would not be used, no matter how technically superior it may be. An accurate and efficient measurement of hand dimensions is crucial for the optimization of the effectiveness and practical use of the gloves.

Previous researchers have focused on hand anthropometry data for development of an improved glove sizing system and on designing a better glove pattern. Robinette and Annis [6], investigated the size variability of Air Force men and women and developed a nine-size system for chemical protective gloves which included a combination of three hand lengths and four hand circumference measurements. In 1988, a US Army hand anthropometric survey report [7] provided comprehensive statistical information of 86 hand dimensions from 2307 samples. However, for development and engineering of a functional sports glove, it is insufficient to only measure the hand dimensions in a static relaxed posture since the significant changes in the hand shape, size and skin surface are present during hand movements. Therefore, databases for hand anthropometry in static relaxed posture cannot be easily used since the glove could restrains hand movements and discomfort may arise due to undesired pressure on the hand.

William [8], revealed that up to an additional of 16% of the total length of material at the back of the hand is required to accommodate the change in skin strain when a fist is made. For example, on a size 9 hand, an increase of 31 mm from an original length of 191 mm can be observed during relaxed hand posture and a power grip posture. To date, only a small number of researches in ergonomic hand tool design and military handwear design have considered the anatomical shape of the hand during different hand movements in the design process [1, 8, 9]. A study specifically focusing on functional sports glove design does not currently exist.

The present study explored the skin relaxed-strain ratio at the back of the hand (dorsal side) as a preliminary investigation for determining the quantitative values of the skin deformation behavior during various sports activities. Data and results obtained from the study will provide valuable preliminary information to be incorporated into sports and functional glove pattern design and engineering for improving the fit, comfort, performance and functionality of a sport glove.

2. Experimental and methodology

2.1. Subjects

A total of thirteen healthy female subjects between the ages of 40-65 years with hand size M were recruited to participate in this study. The subjects chosen had no major injury or trauma to their right hand. The study was approved by RMIT University Human Research Ethics committee. The ranges of hand length and hand circumference of the right hand of the subjects were:

- Hand length: 190 mm – 220 mm
- Hand circumference: 200 mm – 225 mm

These two key dimensions (hand length and hand circumference) were selected based on the literature and industry practice of a glove design sizing system which uses one or two of these key dimensions to define their size categories. The key dimensions selected for this study were consistent with literature [10] which was size M.

Before the hand measurement process, each subject was informed of the whole test procedure, action they should take during the process and the pose for taking measurement. Each subject was also informed about the purpose of the study and the method of maintaining confidentiality.

2.2. Experimental procedure

The right hand of each subject was scanned in relaxed posture and two dynamic postures (grip hand posture and power grip hand posture) as shown in Figure 1. In the relaxed hand posture, subjects were asked to relax their hand on the glass plate of the scanner with fingers abducted. For the grip hand posture, subjects were asked to grip a plastic ball without additional effort or force applied to the ball in order to mimic the hand while holding a bat or a club. For the power grip position, subjects were asked to clench their fist in order to mimic the hand while holding a bat or a club where additional force is required to hold the equipment.

Measurement of the skin relaxed-strain ratio corresponding to the above mentioned postures were taken at the dorsal side of the hand only. The study focusses on the dorsal side of the hand due to the significant deformation characteristics which can be seen on the dorsal side of the hand during various sport activities. In most activities related to sports, the skin at dorsal side of the hand stretches whereas the skin at palmar side of the hand contract.

2.3. Data collection and analysis

A 3D INFOOT scanner (I-Ware Laboratory Co. Ltd.; Japan) which is capable of repeatable and non-contact measurements was used to scan the subject's right hand. The scan speed was 15mm/sec and scanned image was saved in Stereolithography (STL) format.

Foam markers were placed on subject's right hand according to the distribution of landmarks (Figure 2) which were used for the division of the hand into 14 segments (Figure 2 and Table 1). Furthermore, areas of the hand were also divided into three regions which were phalangeal, metacarpal and carpal.

The distance between two landmark points was calculated using Geomagic Studio 12 (Raindrop Geomagic, Research Triangle Park, NC, USA). Each measurement was repeated three times to calculate the mean and to reduce measurement error. The distances between the landmarks which were collected using the software were used to calculate the deformation (skin relaxed-strain ratio, λ) according to the formula:

$$\lambda = \frac{b - a}{a} \times 100 \tag{1}$$

Where λ (%) is a skin relaxed-strain ratio, *b* (mm) represents the distance between the landmarks in one particular dynamic posture and *a* (mm), is the distance between the landmarks in a relaxed posture [11].

Statistical Package for Social Sciences (SPSS) statistics Version 22 was used to analyze the data. One-way ANOVA was used to identify the significant differences among the postures. All of the significance levels were set at $p<0.05$.

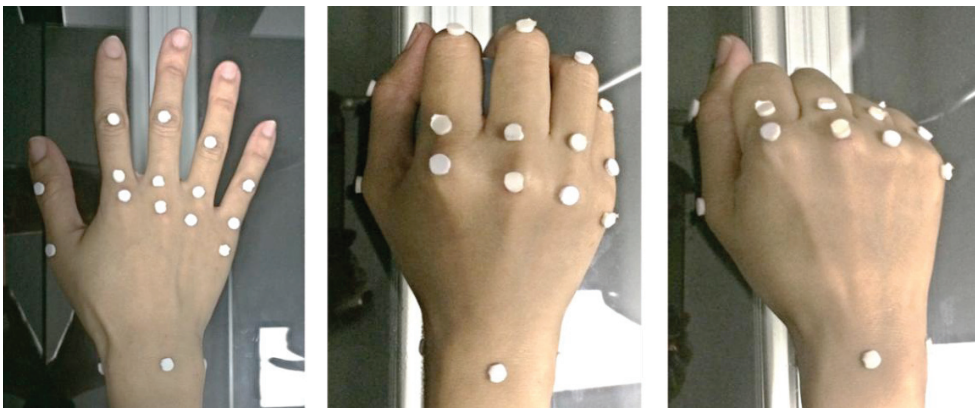

Fig. 1. The three postures used in the study: relaxed posture, grip posture and power grip posture.

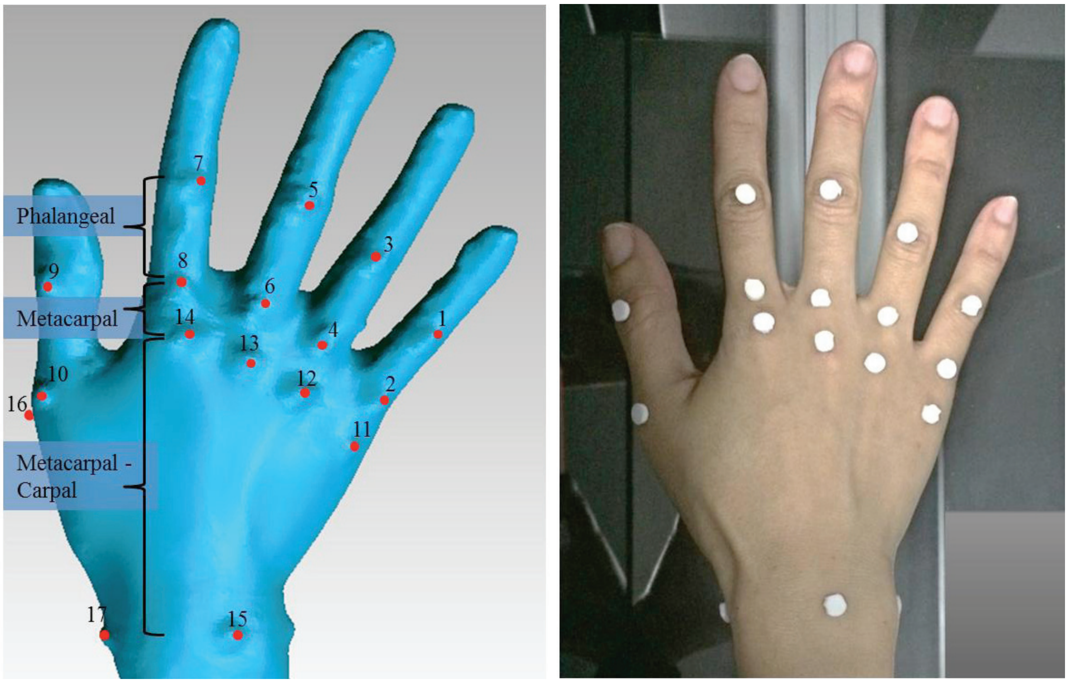

Fig. 2. Distribution of landmarks in Geomagic Studio (left) and on subject's hand (right).

Table 1. Various regions and segments of hand created for this study

Hand regions		Segment number				
Phalangeal	Proximal interphalangeal - finger root	1 - 2	3 - 4	5 - 6	7 - 8	9 - 10
Metacarpal	Finger root - metacarpal	2 - 11	4 - 12	6 - 13	8 - 14	
Metacarpal - carpal	Metacarpal - proximal of wrist	11 - 15	12 - 15	13 - 15	14 - 15	16 - 17

3. Results

Based on multiple comparisons among the postures, the metacarpal region showed the greatest change in skin relaxed-strain ratio which ranged between 38% - 103%. The corresponding values in phalangeal area for the dynamic postures ranged between 18% - 47%. However, there were minimal change in skin relaxed-strain ratio can be seen in the metacarpal - carpal region, which ranged only between 5% - 13%. Analysis of the comparative measurement using one-way ANOVA showed that there was a significant different between the postures and skin relaxed-strain ratio for almost all of the segments except in segment (4 - 12) ($p = 0.219$), segment (12 - 15) ($p = 0.080$), segment (13 - 15) ($p = 0.070$), segment (14- 15) ($p = 0.083$) (Table 2).

Table 2. Multiple comparisons of skin relaxed-strain ratios of hand (one-way ANOVA).

Hand regions	Point number	Grip	Power Grip	F- value	P - value
Phalangeal	1 - 2	26.7185	47.0233	28.455	0.000*
	3 - 4	18.2540	38.6301	43.141	0.000*
	5 - 6	22.8489	32.9528	8.112	0.009*
	7 - 8	22.2613	35.4044	11.074	0.003*
	9 - 10	15.6011	28.2165	10.836	0.003*
Metacarpal	2 - 11	70.5708	102.7669	5.743	0.025*
	4 - 12	37.6447	54.7056	1.595	0.219
	6 - 13	41.6367	65.1931	5.127	0.033*
	8 - 14	41.6903	75.1192	5.261	0.031*
Metacarpal - Carpal	11 - 15	5.4526	8.5324	7.944	0.010*
	12 - 15	5.4329	8.0959	3.339	0.080
	13 - 15	6.8774	10.0648	3.592	0.070
	14 - 15	8.9502	12.2579	3.269	0.083
	10 - 16	7.7692	12.6905	10.293	0.004*

- Figure 3 is the skin relaxed-strain ratio in the two experimental dynamic postures. The skin relaxed-strain ratio of segment number 2 - 11 at metacarpal region recorded the highest deformations which were 70.57% in grip posture and 102.77% in power grip posture. It is evident from Figure 3 that the metacarpal regions recorded significantly higher skin relaxed-strain ratio compared to Phalangeal and Metacarpal - Carpal regions. The corresponding values at segment number 12 - 15, 13 - 15, and 14 - 15 in Metacarpal – Carpal region showed minimal change in skin relaxed-strain ratio and the analysis of the comparative measurement using one-way ANOVA showed no significant differences between the dynamic postures and the skin relaxed-strain ratio.

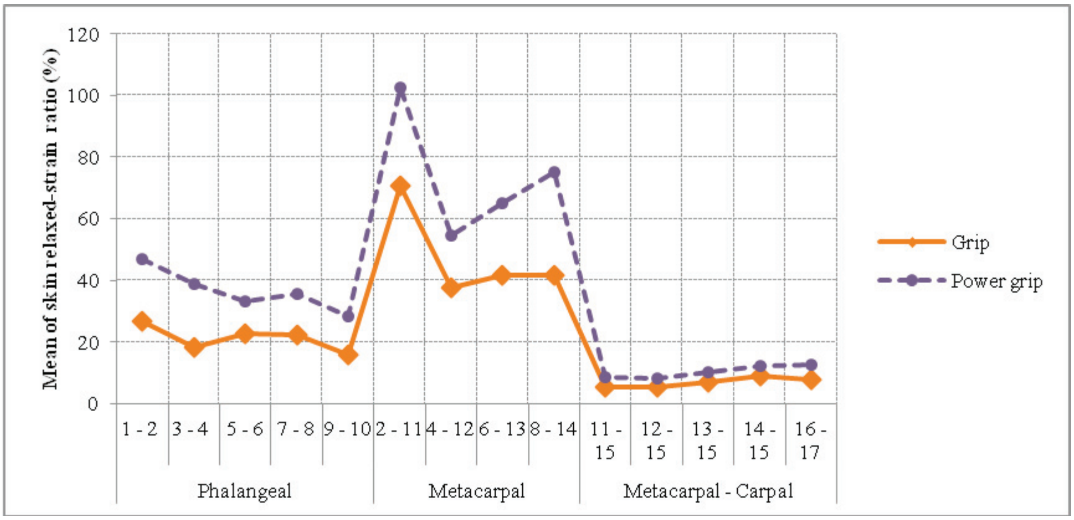

Fig. 3. Skin relaxed-strain ratio (%) in different dynamic postures.

4. Discussion and Conclusions

3D scanners used to capture anthropometric measurements are now becoming a common research tool in apparel; however research in functional sports gloves area is still limited. Understanding how the hand measurement change in dynamic postures can give the designers and manufacturers useful information for designing a functional sport glove that will move and fit well in different level of sports activities, thus providing comfort to the wearer. The study on skin deformation behaviour of the hand during various sports activities is very crucial when designing a tight-fit glove. The changes in skin relaxed-strain ratio will affect the fit of the gloves especially when the hand is in a power grip position, where a higher skin relaxed-strain ratio can be observed in this study. Gloves that fit tightly in a relaxed position will be even tighter in power grip position and therefore induce higher pressure to the hand. This may impact user's hand movement, grip performance and ease of equipment manipulation [12].

The results from this study showed that the metacarpal regions had significantly higher skin relaxed-strain ratio than the phalangeal region and metacarpal-carpal region in both dynamic postures. These findings can provide valuable preliminary information to be incorporated into sports and functional glove pattern design for improving the fit, comfort, performance and functionality of a sport glove. However, further study is needed to determine the skin deformation behavior not only in vertical regions but also in horizontal region, as well as the surface area changes in different hand regions.

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