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Development of a it-Matching App: Validation of 3-D Scanning Applications

Jasna Rosser-Williams
University Of Alabama At Birmingham

DEVELOPMENT OF A FIT-MATCHING APP: VALIDATION OF 3-D SCANNING APPLICATIONS

by

JASNA ROSSER-WILLIAMS

CLADIU LUNGU, COMMITTEE CHAIR
JONGHWA OH
KRISTINA ZIEROLD

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JASNA ROSSER-WILLIAMS

INDUSTRIAL HYGIENE

ABSTRACT

According to the National Institute of Occupational Health and Safety (NIOSH), each day nearly 2,000 workers sustain a job-related eye injury that requires medical treatment. It has been reported that the cause of these eye injuries is frequently due to workers not wearing eye protection because it does not fit properly on their faces. To improve the fit of eye protection, we are aiming to develop a fit matching application (app) which will identify the wearers' better-fitting safety eyewear using 3D technology. We have successfully tested the feasibility of the use of commercially available 3D scanning apps using a mannequin head to integrate into the app we develop. However, such scanning apps need to be tested with actual human faces whose dimensions and texture are different from mannequin faces. The purpose of the present study was to validate the accuracy of 3D scanning apps for use in identification of better-fitting safety eyewear for the wearer to help reduce eye injuries. This study consisted of three steps: scanning of a participant's head using two commercially available 3D scanning apps, scanning of participant's head using a high precision scanner, and comparison of the app data with the scanner data. Fifteen participants representing four races/ethnicities, African American, Caucasian, Hispanic/Latino, and Asian, were recruited for the study. Approximately half (N=8) of them were women. Nineteen facial landmarks were located on the subjects' face using a dermographic pen and eyeliner and each individual's head was scanned with two 3D scanning smartphone applications, Polycam and Metascan, and one high precision 3D scanner. Seven facial dimensions were measured including bizygomatic breadth, nasal root breadth, morphological nose breadth, anatomical nose breadth, inner canthal distance, outer canthal distance, and maximum frontal breadth on images obtained from the scanning apps and scanner based on the landmarks in a computer aided design (CAD) program. Friedman's Test for non-parametric repeated measure test was conducted on 15 individuals to examine the accuracy of 3D scanning apps in seven anthropometric measurements compared to the high precision 3D scanner. Results showed that the 3D scanning smartphone apps and the high precision 3D scanner showed no significant differences in all seven measurements (p=0.3679-0.9636), indicating that the 3D scanning apps provide similar results to the high precision scanner. We conclude that using the two smartphone 3D scanning apps to integrate into a fit-matching app we develop is feasible.

ACKNOWLEDGMENTS

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INTRODUCTION

Eye injury/trauma is a universal issue in occupational settings. According to the National Institute of Occupational Health and Safety (NIOSH), each day about 2,000 workers sustain a job-related eye injury that requires medical treatment (CDC, 2013). The Bureau of Labor Statistics (BLS) reported 3 out of 5 injuries occurred to individuals who were not wearing eye protection (Eye protection in the workplace,1986). Studies have been conducted to find emergent factors as to why individuals are not wearing personal protective eyewear. The most common factors that arose were lack of fit and comfort and negative effects on eye vision from fogging and scratching (Lombardi, 2009). On the other hand, 40% of workers that sustained eye injuries were wearing personal protective eyewear. However, in many cases an object or substance went around or under the protection being worn (Eye protection in the workplace,1986), which furthermore indicates the fit issue of protective eyewear. All the above strongly suggest a need for workers to identify and properly wear better-fitting eyewear which could substantially help reduce the risk of eye injury.

Eye protection such as spectacles and goggles have been shown to be highly effective when worn and fitted properly in preventing an impact hazard (Mancini et al., 2005, Forst et al., 2006, Lipscomb, 2000). A review of effective interventions used to mitigate risk of eye injuries observed that both the rate of eye injury and the loss of work time can be reduced by 50% or more when protective eyewear is worn (Lipscomb, 2006). In a study conducted by Lombardi et. al., it was stated that about 60% of work-related eye injuries are related to lack of usage or using the wrong choice of personal protective equipment (PPE) during the time of injury (Lombardi et. al., 2009).

The Occupational Safety and Health Administration (OSHA) currently does not have any criteria that requires safety eyewear to be manufactured in diverse sizes. ANSI/ISEA Z87.1-2020 standard: Occupational and Educational Personal Eye and Face Protection Devices establishes criteria for using, testing, and marking, choosing, and maintaining protective eyewear to minimize eye injuries (ANSI/ISEA, 2020). While these criteria are vital and relevant to protecting individuals at work, there is a lack of research on manufacturing protective eyewear based on different anthropometric measurements of workers. 3D scanning technology is an innovative way that is being used to investigate diverse facial dimensions so that protective eyewear can provide the best fit for individuals to be protected against eye injuries. Currently, this type of 3D scanning technology has a multitude of real-world applications, including use in industrial design, engineering, manufacturing, medically and recreationally. Without this technology individuals would have to rely on outdated methods of measuring that could be time consuming and more costly. In the medical field, 3D scanning has been used to measure the effectiveness of facial surgeries by comparing before and after 3D scanned images of patient's heads by measuring differences (Chong Et al., 2021).

Our industrial hygiene (IH) research group has been working on the development of a fit-matching application using 3D technology to enable workers to identify better-fitting safety eyewear based on the individual's facial dimensions. In a previous study, the feasibility of using current 3D technology, including 3D scanning apps and a 3D laser scanner, was examined to identify better-fitting safety eyewear using the physical NIOSH headforms (Thomas Et al., 2019). In the study, three different 3D scanning apps on a smartphone were tested to determine the best app which could produce the most efficient images of the two NIOSH headforms (i.e., short/wide and long/narrow). After determining the best app, a database of safety eyewear was established by the researchers by scanning a variety of safety spectacles using a light scanner. Best pairs of safety spectacles for each headform size were selected by comparing anthropometric and gap measurement data. The conclusion of this study was that using 3D scanning technology was successful in identifying better fitting safety eyewear.

The commercially available 3D scanning apps which will be integrated into the app that our research group is developing need to be tested for their performance with actual human subjects with diverse facial shapes. Therefore, the purpose of this study was to evaluate the accuracy of 3D scanning applications for use in identification of better-fitting safety eyewear for the wearer to help reduce eye injuries.

METHODS

Participant recruitment and sample make-up

Research participants were recruited via email with a flyer attached, posted flyers on bulletin boards, and reached out to UAB students and employees who are over 18 years old. IRB approval was obtained (IRB- 300008427) and participants were provided gift cards for their time and effort in participating in the study.

In this study, research participants, who do not wear prescription eyewear, representing four races/ethnicities, African American, Caucasian, Hispanic/Latino, and Asian were recruited. In each category ~4 participants were targeted with half of them being women, making a total of 15 participants. Written informed consent form was obtained from each participant before proceeding with a 3D scanning session. Although the target number of participants was determined based on the limited time of this study, we expect that the suggested number and composition of participants will provide us an introductory understanding of diverse anthropometric dimensions from different races/ethnicities to compare/match with existing eyewear dimensions.

Overall study Design

This study consisted of three steps: (1) scanning of a participant's head using two 3D scanning apps, (2) scanning of a participant's head using a high precision scanner, and (3) comparison of the app data with the scanner data. Two commercially available smartphone 3D scanning apps, Polycam (Polycam, Inc.) and Metascan-3D Scanner (Abound Labs Inc.), were used to 3D scan the subjects' heads. These two 3-D scanning apps were chosen based on the quality of the images of the apps examined prior to this study.

During the scanning, nineteen landmarks (Figure 1), including right/left zygion (z), sellion (s), right/left maxillofrontale (mf), right/left alare (al), right/left ala curvature point (ac), right/left medial (inner) canthus (mc), right/left lateral (outer) canthus (lc), right/left zygofrontale (zf), right/left otobasion superius (os), pronasale (pn), and subnasale (sn),

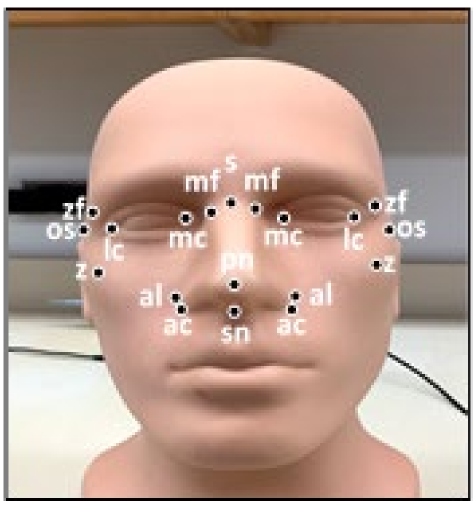

Figure 1.
19 Landmarks

were located on the subjects' heads using dermographic pen (or eyeliner) and adhesive paper dots to help the identification of the landmarks in the scanned images. Once all landmarks were located, each subject's head was scanned with the scanning apps by rotating a smartphone around the subject at 220-360°. The measurements made are defined in Table 1

Table 1. *Seven anthropometric measurements and definitions*

Measurement Names	Definitions
Bizygomatic Breadth (Z)	Maximum horizontal breadth of the face between zygomatic arches
Nasal Root Breadth (Mf)	Horizontal breadth of the nose at the level of the deepest depression in the root and at a depth equal to one half the distance from the bridge of the nose to the eyes
Morphological Nose Breadth (Al)	Straight line distance between the right and left alare on the sides of the nostrils
Anatomical Nose Breadth (Ac)	Linear distance measured between each alare curvature point at the most lateral spot of the curved baseline of the alare
Inner Canthal Distance (Mc)	Distance between the two medial canthi of the eyes
Outer Canthal Distance (Lc)	Distance between the lateral canthi of the eyes
Maximum Frontal Breadth (Zf)	Straight line distance between the left and right zygofrontale landmarks at the upper margin of each bony eye socket

Metascan 3D application procedure

The scanning procedure using Metascan 3D Scanner phone app was as follows: The research participant was seated in an upright position with feet on the floor remaining as still as possible. The Metascan 3D scanning phone application was opened, and the "+" mark was selected to begin a new scan. Then the photo option is selected, and the research assistant took 80 images of the research participant's head while rotating 220-360 degrees around the research participant's head. Once all photos were taken, the "done" selection is selected and the 80 images are uploaded and processed within the app. The images take ~15 minutes to process before the 3D scanned image is complete. Lastly, the image is exported as an obj file and sent to upload into a CAD software for measurement.

Polycam 3D application procedure

The scanning procedure using Polycam 3D scanning phone app was as follows: The research participant was seated in an upright position with feet on the floor remaining as still as possible. The Polycam app was opened, and the "+" mark was selected to begin a new scan and the camera option was selected. Then the research assistant took 80 images of the research participants head while rotating 220-360 degrees around the research participant's head. The "done" selection is selected, the detail is optimized, and the object masking selection is turned on to prevent the background of the 3D scan from being in the final 3D image. The images were then uploaded and processed for ~15 minutes. After the image is complete it is exported as an obj file and sent to upload into a CAD software program for measurement.

Manual measurement of bizygomatic breadth

After the scanning procedures was completed, bizygomatic breadth of the subject was measured using a digital spreading caliper (iGang, San Clemente, CA) and compared with the data (i.e., bizygomatic breadth) obtained from the scanning apps for an initial validation of the scanning apps.

High precision 3D scanner procedure

For the second step, subjects' heads were scanned with a high-precision 3D scanner (EinScan Pro 2X, Shining 3D, Hangzhou, China) in rapid scanning handheld mode while rotating it (220-360°) around the subject's head. Before beginning each scanning session, calibration of the high-precision 3D scanner was completed to ensure high accuracy. The accuracy in the handheld rapid scan mode is up to 0.1 millimeters according to the manufacturer. Calibration was performed by completing all five prompted steps that require the manual turning of the calibration board between each step within the scanning software while holding the scanner in a vertical position to cover the calibration board provided by the manufacturer. Lastly, a white balance calibration was completed by following the prompts within the software. This entire process from start to finish takes approximately thirteen minutes to complete. All the calibration steps were completed prior to each scanning session.

Measuring of the seven anthropometric facial measurements

Lastly, seven facial dimensions from the images obtained using the scanning apps, including bizygomatic breadth, nasal root breadth, morphological nose breadth, anatomical nose breadth, inner canthal distance, outer canthal distance, and maximum frontal breadth, were measured based on 15 facial landmarks, including right/left zygion (z), sellion (s), right/left maxillofrontale (mf), right/left alare (al), right/left ala curvature point (ac), right/left medial (inner) canthus (mc), right/left lateral (outer) canthus (lc), right/left zygofrontale (zf) (Figure 1).

The six measurements except maximum frontal breadth are the dimensions important to eye and face protection devices defined by the ISO TC94 SC6 Committee (Niezgoda et al., 2015) while maximum frontal breadth is expected to better explain the fit to the frame width of the eyewear. The measurements were performed using computer aided design (CAD) software, Meshmixer (Autodesk Inc, Mill Valley, California), and repeated with the data obtained using the 3D scanner for comparison. The remaining 4 landmarks are to be used for further investigations on the fit of eyewear.

Measurement steps in the CAD software program

First, the image was imported from the desktop folder as an OBJ file to ensure accurate color is displayed. The mage was scaled to life-size dimensions by selecting the units/dimensions tab and setting units to millimeters (mm). Measurements were taken after pointing and clicking two landmarks needed to obtain each measurement.

Statistical analysis

Statistical analysis was completed using Stata Statistical Software (Release 17.0, StataCorp LLC, College Station, TX). Friedman's test for non-parametric repeated measures was used to examine the differences in seven anthropometric measurements between three different scanning methods (i.e., two scanning apps and one high precision 3D scanner).

RESULTS

Table 2. *Demographic information of the participants in the study*

Subject #	Sex	Race/Ethnicity
1	Male	Caucasian
2	Male	Asian
3	Female	Caucasian
4	Male	African American
5	Male	Hispanic/Latino
6	Female	Asian
7	Female	African American
8	Female	African American
9	Female	Hispanic/Latino
10	Female	Asian
11	Male	Asian
12	Female	Hispanic/Latino
13	Male	Caucasian
14	Male	Hispanic/Latino
15	Female	Caucasian

Table 2 lists demographic information of the participants in the study. In each race/ethnicity category, 4 participants with equal sex distribution (i.e., 2 males and 2 females) were in the study except African American (i.e., 1 male and 2 females).

Table 3 reports all measurement data derived from taking measurements in the CAD software program. Figures 2-8 graphically show each anthropometric measurement grouped by subject and 3-D scanning methods. The maximum and minimum ranges of variation in millimeters (mm) for all seven anthropometric measurements are as follows: minimum 0 mm, maximum 0.2 mm for bizygomatic breadth (z), minimum 0 mm, maximum 0.6 mm for nasal root breadth (mf), minimum 0 mm, maximum 2.4 mm for morphological nose breadth (al), minimum 0 mm, maximum 1.2 mm for anatomical nose breadth, minimum 0 mm, maximum 1.1 mm for inner canthal distance, minimum 0 mm, maximum 0.4 mm for outer canthal distance (lc), minimum 0 mm, maximum 0.7 mm for maximum frontal breadth (zf).

The results for seven measurements using the Friedman test are as follows: Q(2)= 1.1818, (p= 0.5538) for bizygomatic breadth (Z), Q (2)= 0.0741 , (p= 0.9636) for Nasal root breadth (Mf), Q(2)= 0.4242, (p= 0.8089) for Morphological nose breadth (Al), Q(2)=0.4828, P=0.7855 for Anatomical nose breadth (Ac), Q (2)= 0.3784, P= 0.8276 for inner canthal distance (Mc), Q(2)= 2.0000, P=0.3679 for outer canthal distance (Lc), Q (2)= 0.9286, P=0.6286 Maximum frontal breadth (Zf).

Table 3. *Meshmixer measurement data from all three 3D scanning methods*

Subject	App	Z(mm)	Mf(mm)	Al(mm)	Ac(mm)	Mc(mm)	Ic(mm)	Zf(mm)
1	Metascan	135.3	18.9	36.2	24.7	29.07	100.3	127.9
1	Poly Cam	135.3	18.9	36.2	24.7	29.07	100.3	127.9
1	High Precision Scanner	135.4	18.3	36.4	24.7	29.6	100.3	127.9
2	Metascan	136.5	16.1	42.2	32.6	33	102	120.2
2	Poly Cam	136.5	16.1	42.2	32.6	33.1	102	120.2
2	High Precision Scanner	136.5	16.1	42.2	32.6	33.1	102	120.2
3	Metascan	115.7	17	35.5	21.7	24.1	86.9	109.4
3	Poly Cam	115.6	17	35.5	21.7	24.1	86.9	109.4
3	High Precision Scanner	115.6	17.2	35.4	21.7	24.1	86.9	109.4
4	Metascan	136.3	17.3	42.8	24.5	33.5	104.2	130.1
4	Poly Cam	136.3	17.3	42.9	24.5	33.5	104.2	129.8
4	High Precision Scanner	136.3	17.3	42.9	24.5	33.5	104.2	130.1
5	Metascan	122.5	15.9	38.1	24	26.5	94.5	117.5
5	Poly Cam	122.4	15.9	38.1	24.1	26.1	94.5	117.6
5	High Precision Scanner	122.5	15.9	38.1	22.9	26.3	95.5	118
6	Metascan	127.5	16.9	38	24	30.4	94.2	117.3
6	Poly Cam	127.5	16.9	37.9	24	30.6	94.2	117.2
6	High Precision Scanner	127.5	16.9	37.9	24	30.6	94.2	117.2
7	Metascan	129.4	23.1	39.6	23.6	37.4	104.2	124.7
7	Poly Cam	129.4	23.2	39.5	23.6	37.3	104.2	124.7
7	High Precision Scanner	129.4	23.2	39.5	23.6	37.3	104.2	124.7
8	Metascan	140.4	20.2	47.8	26.7	32.6	108.1	129.4
8	Poly Cam	140.4	20.2	47.8	26.4	33.7	108	129.4
8	High Precision Scanner	140.4	20.2	47.8	26.5	33.6	108.1	129.4
9	Metascan	115.9	19.9	36.4	21.9	29.3	90.5	109.9
9	Poly Cam	115.9	19.8	36.4	21.9	29.3	90.5	109.7
9	High Precision Scanner	115.9	19.6	36.5	21.7	29.1	90.2	109.2
10	Metascan	123.5	15.8	35.9	20.5	30.3	95.7	116.2
10	Poly Cam	123.5	15.8	35.9	20.9	30.3	95.7	116.2
10	High Precision Scanner	123.5	15.8	35.9	20.9	30.3	95.7	116.2
11	Metascan	135.5	23.9	42.7	23.7	34.5	100.2	124.6
11	Poly Cam	135.6	23.9	42.7	23.7	34.5	100.2	124.6
11	High Precision Scanner	135.6	23.9	42.7	23.7	34.5	100.2	124.6
12	Metascan	133.2	21	35.2	17.4	29.6	98.3	122.5
12	Poly Cam	133.1	20.7	35.7	17.4	29.6	98.7	123
12	High Precision Scanner	133.3	20.8	34.9	17.6	30	98.5	122.5
13	Metascan	122.5	17.2	38.5	23	31.2	96	115
13	Poly Cam	122.6	17.2	38.4	22.9	32.2	96.1	115.2
13	High Precision Scanner	122.5	17.3	36.1	22.7	32.1	96.1	114.9
14	Metascan	137.5	18.5	44.3	21.8	31.6	106.4	131.3
14	Poly Cam	137.5	18.5	44.3	21.7	31.6	106.4	131.4
14	High Precision Scanner	137.5	18.4	44.2	21.6	31	106.4	131.3
15	Metascan	124.3	17.2	32.1	16.7	28.4	95.5	115.8
15	Poly Cam	124.2	17.7	32.3	16.9	28.3	95.6	115.4
15	High Precision Scanner	124.2	17.6	32.4	17	28.2	95.6	115.5

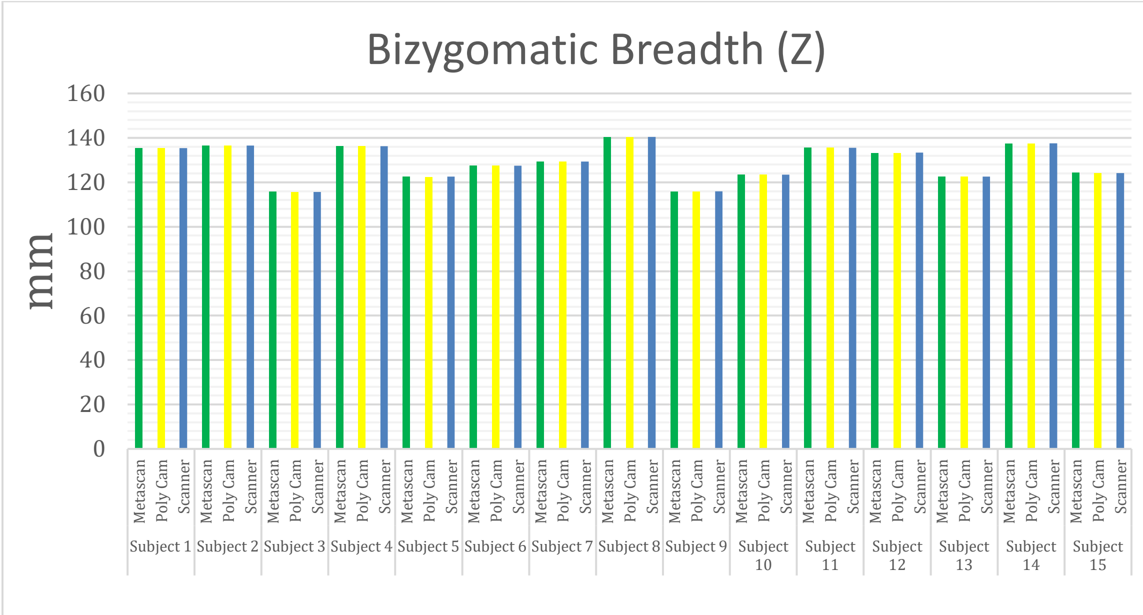

Figure 2

Bizygomatic measurements from all 3-D scanning methods

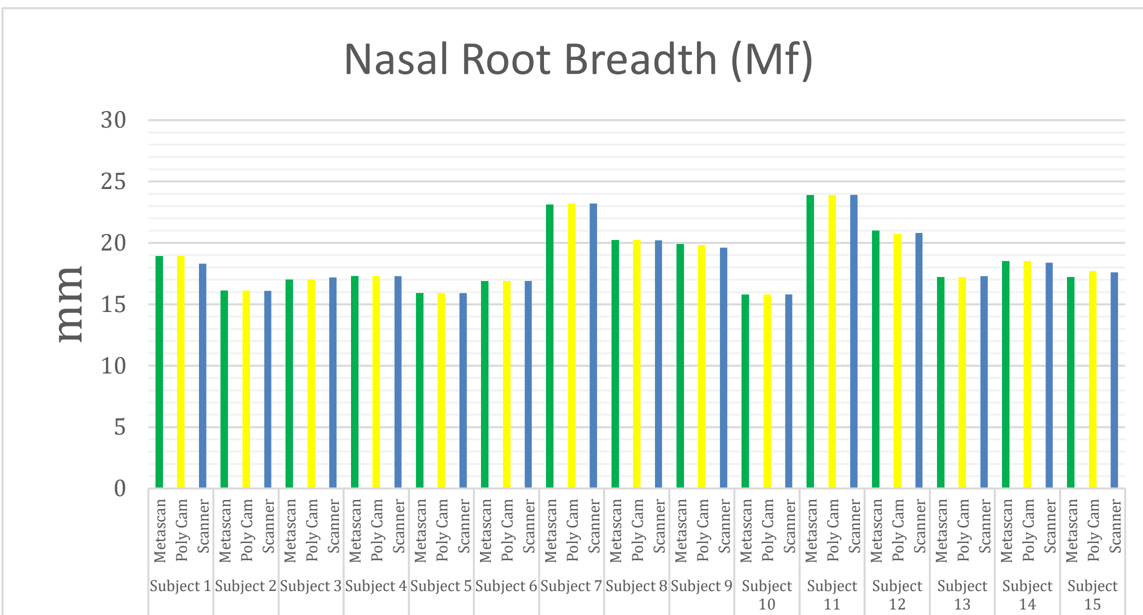

Figure 3

Nasal Root Breadth measurements of all 3-D scanning methods

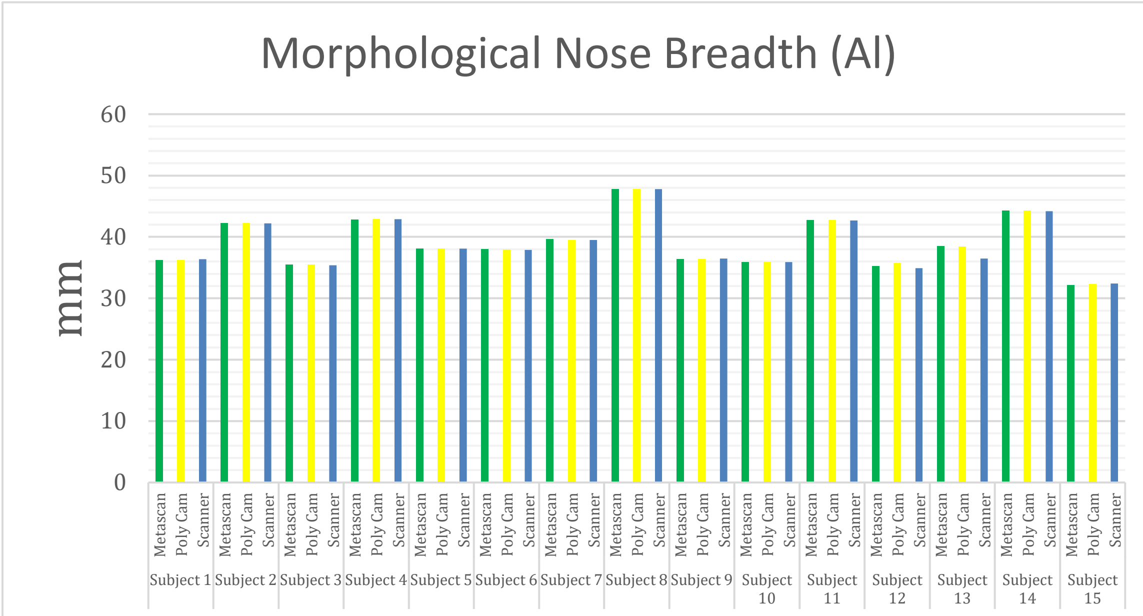

Figure 4

Morphological nose breadth measurements from all 3-D scanning methods

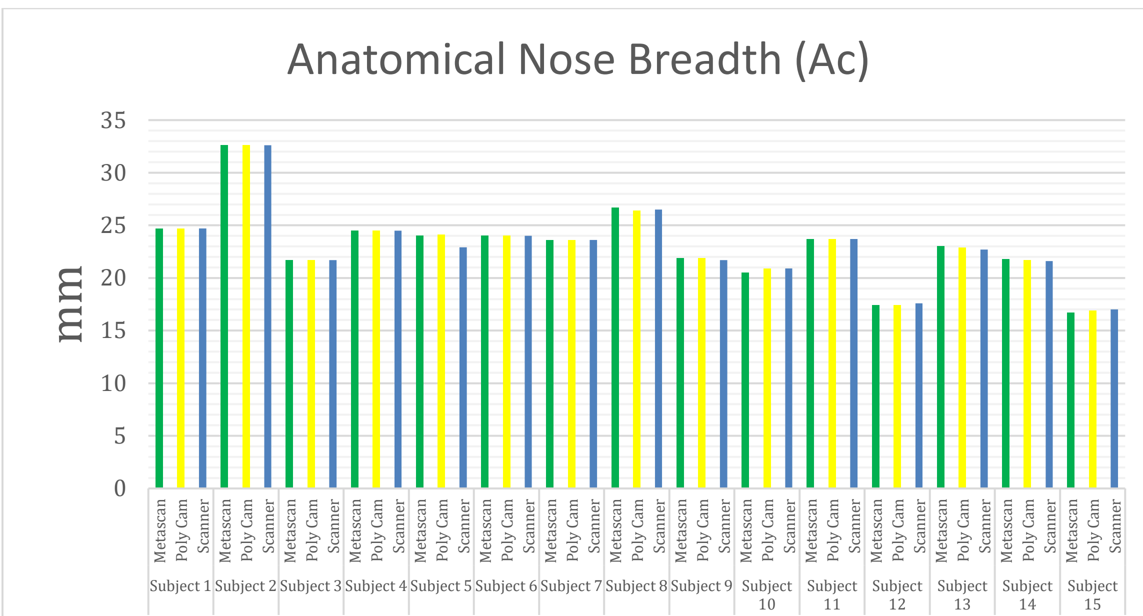

Figure 5

Anatomical nose breadth measurements of all 3-D scanning methods

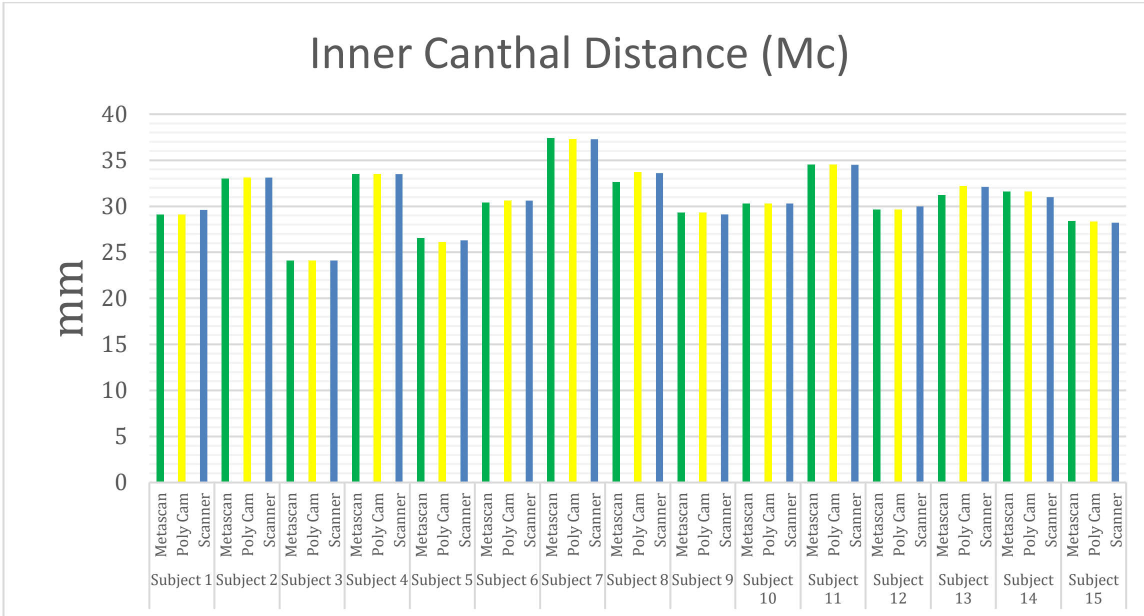

Figure 6

Inner canthal distance measurements of all 3-D scanning methods

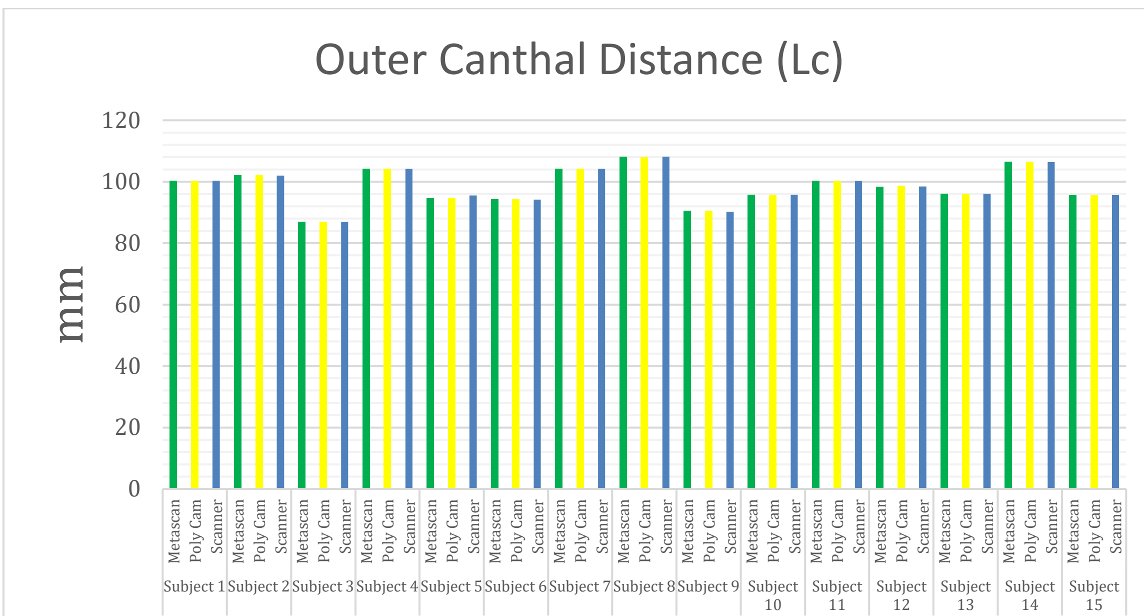

Figure 7

Outer canthal distance measurements of all 3-D scanning methods

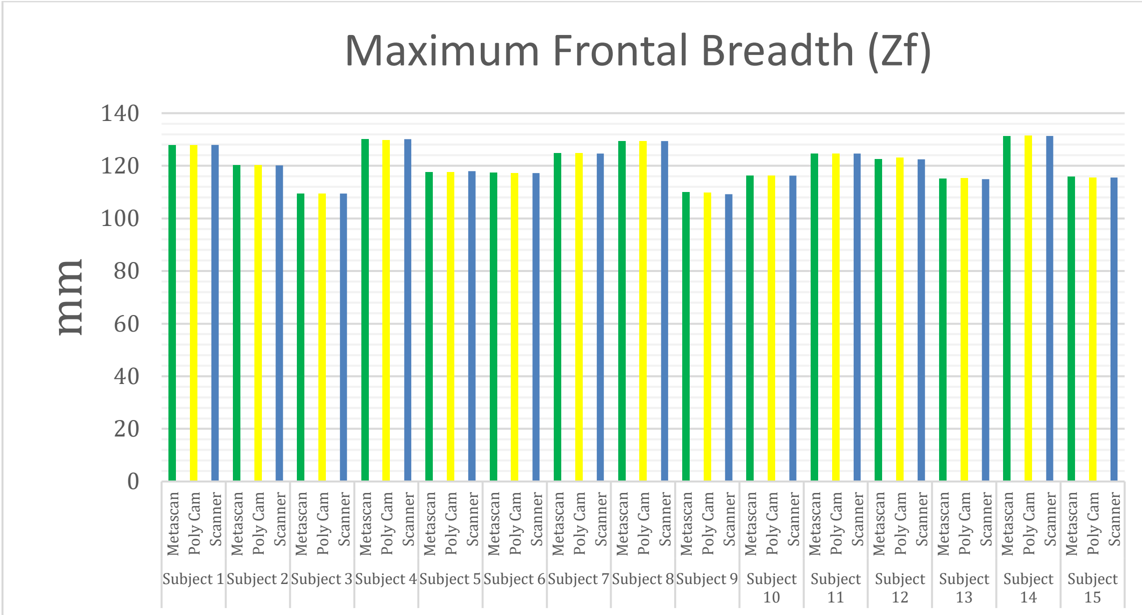

Figure 8

Maximum frontal breadth measurements of all 3-D scanning methods

DISCUSSION

The data on seven anthropometric measurements from 15 subjects obtained from the two 3D scanning applications and the high-precision 3D scanner showed that the 3D scanning applications produce very close results to the high-precision scanner results in the seven anthropometric measurements; no statistical difference was found in all the seven measurements between the scanning methods. These results indicate that the two scanning apps can further be used in the development of a fit-matching application our research group is developing. This research will help future research to develop a fit-matching app which will allow the wearer to select better fitting safety eyewear that closely matches their facial dimensions to protect them from eye injuries.

Measurement variations in each measurement were mainly contributed by the difficulty of visually seeing the marked facial landmarks on participants faces due to facial structure. The largest variation of measurement observed was subject 13 where a 2.4-mm difference in morphological nose breadth (al) was observed. The Metascan measurement was 38.5 mm, Polycam 38.4 mm, and the scanner 36.1 mm. It is also important to mention that the landmarks marked with a dermographic pen can become less recognizable when placing the marking on human faces due to the structure of the individual's nose. In general, male participants' anthropometric measurements were larger than women. Asian male faces generally had higher bizygomatic breadth (Z) measurements than other races/ethnicities.

Both 3D scanning applications are user friendly and require 80 images of the research participants' heads to capture and output a quality image that can be uploaded and measured into the CAD software program. Of the two 3D scanning phone applications, Polycam was easier to use and provided a quicker output image at about ~10 minutes per scan. It is important to mention that ±2 mm numerical variability when measuring is presumed to be because of facial structure causing landmarks to become disfigured and human error when operating all 3-D scanning methods.

A few limitations must be addressed in conducting this research. The limited number of study participants could not necessarily reflect the diversity of facial measurements in our database. Although the accuracy of the scanning apps has been examined in our previous studies, there is a possibility that the apps could give inaccurate results due to the difficulties in locating certain landmarks due to the facial structure. You might want to mention the human error and the solutions you mentioned during the discussion today.

CONCLUSION

In this study, the accuracy of two 3D scanning applications, Metascan 3D and Polycam, was successfully confirmed by conducting anthropometric measurements of actual human faces in a CAD software program, indicating the feasibility of using the two scanning apps to integrate into a fit-matching app we develop. All the seven anthropometric measurements obtained from the scanning apps were not statistically significantly different from those obtained from the high-previous scanner.

This research will provide the foundation and a database for the future development of a fit-matching application with which workers will be able to scan their faces and choose the appropriate eyewear based on their anthropometric measurements. The development of a fit-matching smart device application will enable wearers to identify better-fitting safety glasses improving the user fit which was the most common reason for not wearing safety eyewear, thus consequently providing more protection from occupational eye injuries. Further investments and research on diverse facial dimensions of the working population could help the protective eyewear manufacturers to produce better-fitting eyewear for the diverse United States workforce.

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