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ASSESSMENT OF ANTHROPOMETRIC METHODS IN HEADSET DESIGN

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Keywords: comfort, anthropometry, ergonomics, human factors

1. Introduction

Current approaches to assess consumer products for usability and comfort often involve expensive user trials. For external ear products such as headsets and bluetooth communication devices comfort is an issue leading to many concepts being rejected at the late stages of the product development process once prototypes are developed and tested. Current databases for anthropometric data e.g. Peoplesize Software [Peoplesize 2008] lack data regarding useful ear dimensions of the external ear area. This paper examines the incorporation of anthropometry in the design of external-ear devices, resulting in a faster development process and better quality products. Anthropometric dataset have been acquired through existing databases and a series of anthropometric methods performed on population samples. The context of the study is to assess the methods to collect data utilising a case study from the ear industry. The intention of this approach is to investigate and evaluate the methods leading to a recommendation of their usage during the different phases of the product development process. The current study explores the complicated relationships between comfort, technology and humans through the assessment of the various methods.

2. Literature review

2.1 Anthropometry

Anthropometry is considered the very ergonomic core of any attempt to resolve the dilemma of "fitting the tasks to the human" [Sanders and McCormick 1993]. In order to better understand the use of anthropometric data to inform design decisions comfort factors were also investigated with respect to external ear devices. The understanding of the ear geometry through the various measurements will lead to the identification of human factors. Current approaches to collect anthropometric data include the use of measurement instruments. Jung and Jung [Jung et al. 2001] provided anthropometric dimensions of ears of Korean subjects using digital calipers. Other methods suggest the use of simple geometric calculations to acquire dimensions from a 2D photograph by setting reference points before taking the photographs. Examples of other relatively noninvasive, 3D imaging techniques include various forms of stereophotogrammetry [Weinberg et al. 2006], more topography techniques [Li 2006] [Ghoddousi et al. 2006] and surface scanning technologies [Hennessy et al. 2002]. For this study there has been a scientific measurement and collection of data of human ears and the application of this data is in the design and evaluation of products.

2.2 Approaching comfort

The term 'comfort' might be used to describe a feeling of contentment, a sense of cosiness, or a state of physical and mental well-being [Chappells et al. 2004]. There is no prior art describing comfort for headsets as much of this knowledge is kept confidential. However, comfort has been investigated for other products like office chairs [Vergara 2002]. These prior studies have provided insight into how comfort is evaluated in other industries and have also provided methodologies which can be utilised.

3. Methodology

Two studies were carried out: a study to compare four methods of acquiring anthropometric data and in addition a smaller, qualitative study to identify factors of comfort. The 30 individuals who participated in the comfort test were all Danish ranging from 23 to 48 years old, with a diversity in professional and financial background. The participants were given three representative ear products (an ear band, a bluetooth earphone and headphones) and were asked to interact with them, that is try them on and off and so on. The participants were timed as well in terms of wearing the products and understanding their functions. Later, they were asked to grade the products and answer questions regarding their impression of the products and their interaction with the products. For the study of the anthropometric methods a number of criteria were defined to facilitate their assessment (see Table 6). From this four methods were selected and applied on a number of individuals as summarised in Table 1.

Table 1. Origin of data

Methods	Participants	Gender	Origin	Age
Instrument Method	120	60 Males	Danish	22 – 68 years
		60 Females		
Photographic Method	80	40 Males	20 Danish	Danish: 39 – 65 years
			20 Greek	
		40 Females	20 Danish	Greek: 20 – 40 years
			20 Greek	
3-D Camera method	1 (Author)	Male	Greek	31 years
Laser method	1 (Author)	Male	Greek	31 years

For the instrument method ear dimensions were measured with the help of a vernier calliper. The photographic method was conducted based on simple photogrammetric principles using digital cameras and an image processing software. For the 3D method a 3D camera system based on digital three-dimensional photogrammetry was utilized. Out of the four methods the laser method was found to be insufficient to persue further due to inaccuracies in the setup. Due to time limitations of this project and the high cost of the 3D camera method it was only possible that a large set of ear data would be collected for two out of the three methods. However, all three methods were assessed against the criteria and the 3D camera method contributed to the product understanding and was used for benchmarking purposes during the comparison of the instrument to the photographic method.
A valuable tool in the processing of the many existing databases was the Peoplesize 2008 Software. The PeopleSize anthropometry dataset uses a large number of original survey datasets in combination. The dataset contains 289 individual body measurements, 9 nationalities, 9 adult age groups (for the Caucasian nationalities:- 18-64, 18-25, 18-39, 25-50, 40-64, 65+, 65-74, 75+, 85+) and over 20,000 participants. The anthropometric measurements of the different datasets on Peoplesize have been compared with the respective dimensions of the earlier examined ear products (they have to comply with the set of human factors) in terms of age, gender, nationality and income (high or low). After having received all the percentiles for the population samples, conclusions are drawn as to how the anthropometric measurements differ in terms of age, gender and so on and how impactful this is on the headset design.

3.1 Understanding the products with the help of the 3D camera method

Initially an attempt was made to understand the ear products. Three representative ear products were selected. Issues of functionality, structure, synthesis of different materials and geometry were identified for the products (see Table 2). The 3-D camera method has been a valuable tool during the product understanding phase. The system consists of one projector and two cameras which are both calibrated. Using a structured design in which patterns are projected onto the object's surface, pixel values are assigned by calculating the exact distance between points on the object's surface and the focal plane of the camera. In this system all visible points are calculated simultaneously in a single capture in a few seconds. Once the scanning has taken place then the two images produced by the two cameras were merged with the help of a 3D modeling software.

Table 2. Product understanding table

	Functionality	Structure	Materials	Geometry
Products				
	The earbud is partially inserted into the ear. The product's ear plug is attached inside the concha. The outer part of the product is in physical touch with the ear connection down to the lobus		Polyester (PET), Polycarbonate (PC), rubber	There has to be a good fit between the bud and the concha. Bud Diameter: **14.80 mm** Vertical Length of outer part of the product: **38.06 mm**
	The ear plug is partially inserted into the ear. The physical connection is made between the ear plug and the concha.		Polyester (PET), Polycarbonate (PC), rubber, velour	There has to be a good fit between the bud and the concha. Bud Diameter: **18.01 mm**
	The bud completely surrounds the ear (circumaural). The two buds are connected with a band which runs around the head.		Thermoplastic polyurethane, velour and velvet	Vertical Length of the bud : **62.00 mm** Measured distance of the band (between the centers of each bud): **334 mm**

The outcome of this is a single 3D model. This scan was then sent to a 3D – printer to produce the physical 3D model of the ear and head from a gypsum- based material, see Figure 1.

Figure 1. 3D scanning process

A fitting process of the products on the 3D model of the head took place which led in the definition of relevant, linear, human factors as seen in Figure 2. The devices were tested on the 3D head and critical areas were identified leading to the following dimensions: L1 is the Concha length, which is the dimension between the top of the ear canal to the bottom of the intertragic incisure. L2 is the pinna length, which is the dimension between the top of the ear canal to the bottom of the intertragic incisure. L3 is the ear-connection length which is the distance from the point to where the pinna is connected to the head and the lower lobule of the ear.

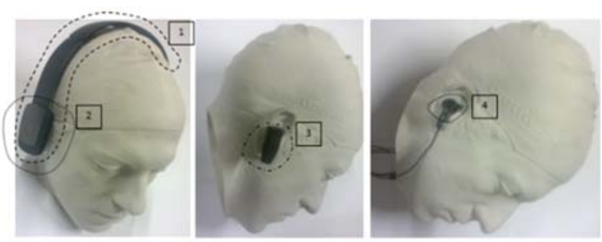

Figure 2. Fitting process

3.2 The instrument and the photographic method

The external ear dimensions defined in the aforementioned section were measured using the vernier caliper Model No 500 – 191 U made by Mitsutoyo Corp. The three dimensions were the pinna length (L1), the ear connection length (L2) and the concha length (L3). The individuals were asked to pose in a sitting position and be relaxed so that they remain as still as possible.

For the photographic method the same three external ear dimensions have been measured. Each subject was asked to pose in a sitting position in front of a white sheet and the head was held so that the subject looked straightforward with the lower borders of the external auditory meati. This had to be checked many times before the measurements took place. Further, a digital millimeter grid (5_5 mm) was superimposed on the photos as seen in Figure 3. The grid was employed so that the size of the ear could be measured from the physical dimensions of the photograph. The horizontal dimension between the camera and the ears was measured. The height between the center of the camera lense and the ground as well as the height between the center of the ear-concha length and the ground had to be the same. Having located reference points on the exact same distance between the camera and the individual´s ears a ratio was calculated, that is the known object's height divided by the physical size of it on the photo. This was the scale multiplier.

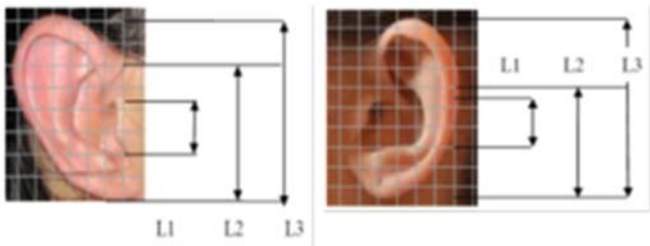

Figure 3. Superimposed photographs and critical ear dimensions

Ear features were then captured using a Sony digital camera (P10, 2048_1536 pixels) in Greece and a Cannon digital camera (DS12, 2048_1536) in Denmark. Editing software was used to optimize brightness, contrast, and size to produce a clear image. Further, a dimension tool was used to create a vertical dimension line that measures the vertical distance between any two landmarks along the y-axis. Thus, ear dimensions could be easily and accurately calculated by multiplying the distances by the ratio. The 3D Camera method contributed in the collection of only one ear sample, which was also measured by the instrument and photographic method. Those common measurements were used to create a benchmark control in order to compare all three methods.

3.2.1 Criteria of the methods to be performed

In order to investigate and evaluate the methods, an assessment of criteria was established through interviews conducted with employees in the ear industry as well as through literature research and investigation of similar execution of the methods from past papers. The criteria were: the accuracy of the methods, the cost (cost of equipment used during the anthropometric method, cost of each time when executing the method, cost of maintenance of the anthropometric equipment), the time (duration of the execution of the actual measurement, the time needed to process the result and the overall time of involvement of the specialized personnel), the level of comfort towards the method, the trained personnel (technical knowledge required for the operation of the equipment, scientific background required for the data analysis and processing, medical personnel required for the execution and approval of method, material, etc,) and an overall effectiveness towards all parameters (how many of the above criteria the method satisfies).

The accuracy of the methods were assessed by the use of a common benchmark control. Cost was assessed through a market investigation and talks with specialized personnel at the collaborating company. During the testing of the methods on the users the individuals were asked questions basically stressing on the biological, physical and physiological impact of the methods on them. For the instrument and photographic method participants were also asked to evaluate the methods themselves and were used when considerating the overall assessment of comfort for the methods. The impacts of the current method on users will be examined and evaluated as follows. The idea behind the issuing of the criteria and the comparison of the methods is to delineate the methods, that is, to arrange them in a way where diversity –if there exists any- could be highlighted. This would eventually lead to a recommendation of choice of use of the methods during the product development process.

3.3 Data Analysis

3.3.1 Analysing the data retrieved by the methods performed

For the 3D Camera method, the 3D Scan was inserted in the 3D modeling software Geomagic Studio Software and the 3D model of the head was retrieved. Through the clipping - plain tool the head was cut and the relevant geometry could be observed (see Figure 4).

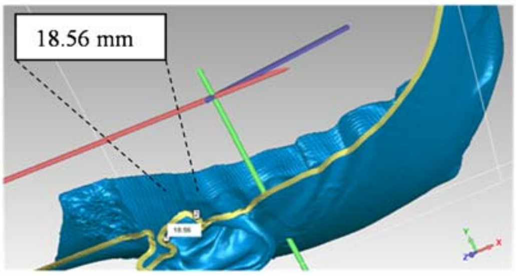

Figure 4. Measuring ear dimensions in Geomagic Software

The acquired data retrieved by the instrument and the photographic method was processed through a series of statistical tools using SPSS 19.0. Two factor analysis of variance (ANOVA) were utilized to determine the effects of gender and age on ear dimensions. For the photographic method, a correlation analysis will also take place to possibly define a relationship between ear dimensions. Correlation should be applied to the most accurate method of the two. So, prior to correlation the methods have to be compared in terms of accuracy, which is also one of the evaluation criteria.

3.3.2 Common benchmark control

One ear has been selected and measured through all three methods. Common sense would dictate that the instruments' accuracy values could give an impression of the methods' potential accuracy. The instruments used in the 3-D Camera method appear to give the most accurate measurement of the ear. In this case, we would have to compare the instrument and the photographic method with the 3-D Camera method. To do this, the measurements of one ear have been plotted taking into account the standard deviation of the measurements as retrieved from the above table. For each dimension as shown below in Figure 5 the length was mapped including the deviations.

The photographic method gave the closest number for all three measurements to the ones taken from the 3-D Camera method. For this reason, we choose to make our correlation analysis with the photographic method. So, in the case of the photographic method tests were performed with age against ear dimensions to identify if higher (55-65 years) and lower age groups (22-32 years old) differ (or not) in their ear geometry.

Age and gender towards ear dimensions were assessed in one test. Correlation tests were performed between the various ear dimensions in order to define the relationships between the ear dimensions. The correlation coefficients will be calculated for the pairs (L1-L2, pinna - ear connection), (L2-L3, ear connection - concha) and (L1-L3, pinna - concha). For the search for an archetypal equation among the ear dimensions a multiple regression model was developed. Three factorial variables were chosen (Pinna length, Ear Connection length and Age) as the independant variables. The concha length was chosen as the dependant variable. It has been investigated whether linear regression is appropriate by referring to the appropriate SPSS output; the linear regression equation has been stated.

In addition, the usefulness of the model, the coefficients, the variability of the model and requirements for the model to work will be discussed.

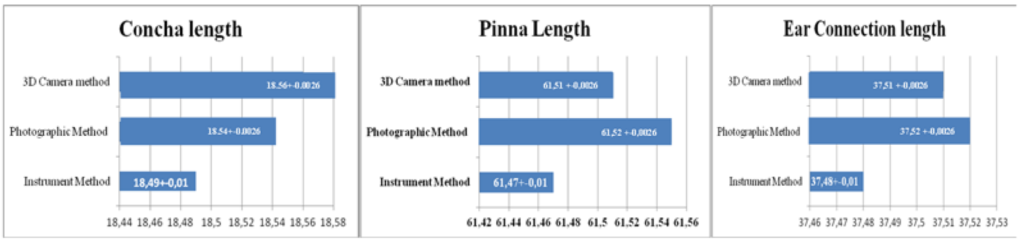

Figure 5. Ear dimensions measured through all three methods

The two methods were compared with each other. The ear dimensions of ten individuals have been measured using the two methods. The individuals chosen for this are all female and show a small range in terms of age. Paired-sample t-tests have been run for each of the three ear dimension. Small differences were observed in all the calculated means. (Pinna- Instrument 48,017, Photographic 47,610, EarConnection – Instr. 40,330, Phot. 40,160 , Concha – Instr. 14,64, Phot. 14,66). The correlation coeficients were extremely high for the three dimensions (Pinna – 0,914 , EarConnection - 0,931 , Concha - 0,924). As for the paired sample tests, all were greater than a=0.05 (Pinna:0,67, Ear Connection: 0,427 , Concha: 0,896) which is the last indication that the means of both methods are significantly not different.

4. Findings

4.1 Reflections on comfort

The observations of users were analysed and it was found that men showed a better understanding towards the functionality of the products compared to women (see Figure 6 for the ear plugs device).

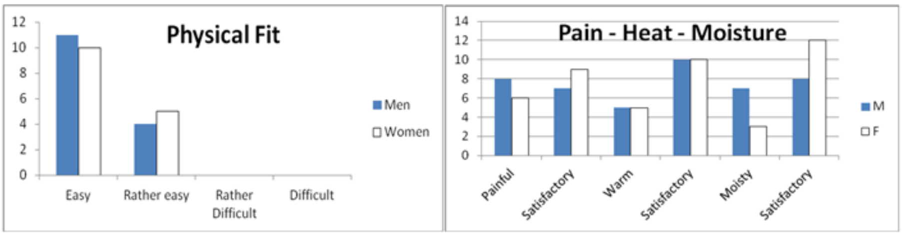

Figure 6. Charts on comfort

The majority did not experience issues of heat or poor fit and they overall seemed satisfied towards the products' comfort factor. Women found the products to be elegant but more masculine. They experienced them as *strict* and *professional.* Some of them experienced issues of heat and poor fit. The physical fit led to discomfort particularly for females. Hence there is a need to better understand the dimensions of the ear.

4.2 Existing databases

Peoplesize 2008 contains anthropometric data including the pinna length of the ear. The corresponding product dimension to the pinna length from the ones seen in the product understanding is the ear bud's length. According to this the bud length is equal to *62 mm.* All the results were summarized in Table 3 of percentiles below.

For British females against income the percentile for both samples is high, which means that with the current designs the length of the bud is too large relative to the females´ pinna length. It can be seen that a 2-mm reduction in the bud´s length will reduce the included percentile to 73.1 for women with high income and the 78.1 for women with low income. In the same sense, for British males a 4-mm increase in the bud´s length is recommended. Regarding age, 90.9 % of British females with high age and 86.4% of British females with low age have a pinna of length equal or smaller than 62 mm. A 2-

mm decrease in the bud´s length is recommended which will apply to the 78.1 percentile for women (40-64 years) and the 71.4 percentile for women in the low age (18-25 years).

Table 3. Table of percentiles

Pinna Length	Income		Age (High:40-64 years, Low:18-25 years)		Gender	Nationality
British Females	High	87.6	High	90.9	89.4	89.4
	Low	90.9	Low	86.4		
British Males	High	27.8	High	34.7	32.1	32.1
	Low	36.8	Low	30.2		
Dutch Females					24.1	24.1
Dutch Males					4.4	4.4

Regarding gender, an anthropometric comparison can be made for both British and Dutch samples. There is a significant difference in the two percentiles which permits us to estimate that the females' sample may have smaller pinnas than the males' sample. Also, for both Dutch males and females the fit would be poor. If samples are compared in regards to nationality, there is a significant difference in the two percentiles which permits us to estimate that the sample of Dutch men and women have larger pinnas than the British males and females accordingly. Percentiles can assist gender - specific as well as nationality - specific design but it is extremely hard to accommodate all users without a large increase in cost. Component-based earphone design should be considered in this case. By leaving the main body of the devices identical, however providing with a variety of different sized rubber prosthetics, variety of products could be secured towards different user groups. Currently Peoplesize offers data for the pinna, however the concha length and ear connection length which are valuable for the ear products are not available. Hence, we need a more effective way to collect the measurements.

4.3 The instrument and phorographic method

4.3.1 Age and gender

The means of all the ear dimensions are larger in males in both methods. In the photographic method results of ANOVA showed that there were statistically significant differences between gender in pinna length ear connection length and slightly for concha length (see Table 4).

Table 4. Statistical results of the two methods

Methods		Gender			Age
		ANOVA	Means (mm)		ANOVA
			Females	Males	
Instrument Method	Pinna	F(1,118) = 50,267, p<0.01	59.77	66.17	
	Concha	F(1,118) = 49,220), p<0.01	16.60	19.16	
	Ear Connection	F(1,118) = 0,238, p = 0,627	39.89	40.22	
Photographic Method	Pinna	F(1,78) = 79,011, p<0.01	50.89	59.53	F(3,116) = 9,701, p<0.01
	Concha	F(1,118) = 6,027), p= 0.016	15.24	15.98	F(3,116) = 1,922, p=0,130

	Ear Connection	F(1,78) = 75,900, p<0.01	40.96	49.02	F(3,116) = 5,917), p<0.01

We conclude that men of this sample have larger pinnas and conchas than women and possibly this is the case for the ear-connection length.

For age, results of ANOVA showed that there were statistically significant differences between age in pinna length and ear connection length but no significant differences have been observed for the ear hole length. Results of ANOVA in the photographic method showed that the pinna and the ear connection tend to grow with age regarding the people of this sample. The coefficients show that there are strong correlations demonstrated between the age categories and the ear dimensions for males. Specifically, between the pinna length and the age categories coefficients are 0,932, whereas for the ear connection length and the concha length they are 0,865 and 0,804 respectively. This clearly indicates that the older group have larger ear dimensions. For females, the coefficients between the pinna, concha and ear connection and the age categories are 0,969, 0,979 and 0,944 respectively. Hence, the older females have larger ear dimensions than the younger females. These assessments imply a linear relationship between factors (age, gender, nationality and so on) and ear dimensions. An attempt will be made to stress on the mathematical form of the aforementioned relationship described in the next session.

4.3.2 Multiple regression model

From the plotted diagrams of the earhole (concha) length towards all the chosen variables (age, ear connection length and pinna length) it is evident that there is a strong positive relationship for all independant variables towards the dependant variable compared to pinna and ear conncetion. This can be assessed by both the visual impression of the scattered points (in the ear connection and pinna the scatter is greater) and the value of the squared R^2 which is higher for age (R^2=0,631), whereas it is lower for ear connection (R^2=0,600) and pinna length (R^2=0,525).

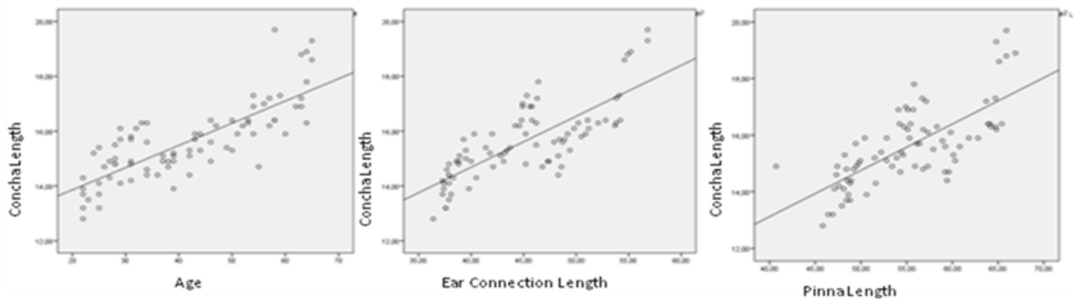

Figure 7. 3D scanning process

Our regression equation would have the following form after the factors before X1, X2 and X3 are being replaced with the b1,b2 and b3 values for coefficients from Table 5 of coefficients below.

$$y = 9.431 - 0.101\ X_1 + 0.211\ X_2 + 0.053\ X3 \quad (1)$$

Looking at the t-column, with an a = 10% level of significance, all p values are less than 10%, which means that age, pinna length and ear connection length are all significantly related to the dependent variable. There seems to be a normal distribution among the residuals which are also independent. A homoscedastic behaviour in the residuals against the predicted values for all dimensions was also observed concluding that the model is in fact useful. Finally the model was tested for variability and it was found that 76.6% of the variability of the concha length can be explained by the variability of the independent variables. If more variables are taken into account this would increase the variability percentage that can be explained by the independent variables.

This model shows that a human dimension can be calculated if a number of factorial and numerical variables is known. This could accelerate the process of collecting anthropometric data.

Table 5. Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	9,431	,754		12,508	,000
Age (b3)	,053	,007	,524	7,545	,000
PinnaLength (b1)	-,101	,046	-,446	-2,175	,033
EarConnectionLength (b2)	,211	,049	,880	4,280	,000

4.4 Observations on the criteria set for the methods

All the findings during the criteria setting towards the methods are summarized in Table 6.
The instrument and photographic method are more cost and time effective hence suitable for fast collection of data and statistical analysis. The 3D camera method however is more suitable for analyzing and observing the ear geometry but leaves room for improvement in terms of time, comfort and cost.

Table 6. Table of criteria

	Accuracy	Cost		Time		Comfort		Personnel	Parameters
Instru-ment method	Instrument: 0.01 mm Method: not significantly different than the photographic method	Cost of Equipment	90€	Time of one cycle	3 min.	Biological	Yes	Not required	All
		Cost of test	-	Result processing	2 min.	Physiological	Yes		
		Cost of maintenance	-	Specialised Personnel	-	Psychological	Yes		
Result	Satisfactory (for fast data collection)	Satisfactory		Satisfactory		Satisfactory		Satisfactory	Satisfactory
Photo-graphic method	Instrument: 0.055 mm	Cost of Equipment	420 €	Time of one cycle	8 min.	Biological	Yes	Image Software skills required	All
		Cost of test	-	Result processing	15min.	Physiological	Yes		
		Cost of maintenance	-	Specialised Personnel	-	Psychological	No		
Result	Satisfactory (for fast data collection)	Satisfactory		Satisfactory		Satisfactory (?)		Satisfactory	Satisfactory
3-D Camera method	Instrument: 0.03 mm	Cost of Equipment	130.000 €	Time of one cycle	40-45 min.	Biological	No	3-D modeling software skills	All
		Cost of test	-	Result processing	30min.	Physiological	No		
		Cost of maintenance	-	Specialised Personnel	1.5 hr	Psychological	No		
Result	Satisfactory	Satisfactory		Not satisfactory		Not satisfactory		Satisfactory	Not satisfactory

5. Conclusion

Three methods of measurement of ear dimensions have been compared. Existing anthropometric dataset was utilized to allow nationality and gender to be further analysed. Dutch and British data was compared, Dutch data was found to be larger than the British data. Significant differences have been identified in gender (male ears are larger than female ears). The percentiles showed that current designs should be redesigned with respect to the dimensions of data leading to improved fit, as currently they exclude large percentiles of users.

All methods were compared with respect to accuracy, time, comfort, etc and it was found that both the instrument and photographic method were time and cost effective, hence more quantitative whereas the 3D camera method was able to provide small databases and was found to be more useful for in depth analysis of data, hence more qualitative.

In addition a mathematical model has been proposed which needs to be further evaluated. Early indications show that this can be a promising approach to collect data if by only collecting a few dimensions by being able to predict the remaining data. If this is feasible this would lead to the possibility of external ear products being assessed for comfort earlier in the product development process, hence reducing cost and time.

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