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Importance of Anthropometry for Designing User-Friendly Devices: Mobile Phones

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Abstract

Hand-size variations and users' satisfaction of mobiles were investigated using anthropometric techniques and structured questionnaire interviews on 160 adult males. A total of 20 hand measurements and mobile phone dimensions were recorded. Special emphasis was given on keypad design factors, which include: key size, shape, layout, texture, simplicity and space between keys. Factor analysis was performed on both the hands separately since significant difference was found in hand dimensions when *T*-test was applied. Amongst various factors hand length, hand breadth, palm length, index finger length, middle finger length, thumb length, and thumb circumference were found to affect the users' grip of mobile handset. One of the recommended improvements is to have larger keys with more space between them for those with large hand-size. The results obtained can be used by mobile phone designers to design user-friendly mobile handsets; for example, mobile phones that suit users with larger hands and thumbs, especially males and the elderly.

Keywords: Hand anthropometry; Ergonomics; Mobile phones

Introduction

With the advent of new technology the way of communication has also evolved many folds-from pigeons as a way of communication through post/telegraph/telephone to wireless contact that gave rise to mobile phones. Mobile phones are long range, portable and wireless electronic device of communication. There is no doubt that the mobile phones have made the life more easy, fast and comfortable. Everyone is in touch with their near and dear ones and also with the outside world. They proved to be a big help as life savers in emergencies. Besides, they are being increasingly used as light terminals to access the internet. The more recent addition of GPS (Global Positioning System) is really a tremendous help to the user as well as to the detective agencies in various situations. The cell phone or mobile phone is such a standard part of everybody's life today that one cannot imagine what life was like before it was invented.

Our survey conducted among the youth and elderly revealed that the physical aspects of the mobile telephones were important for the users. Among the youth, having the correct style and type of device were seen as being important in one's presentation of self while the elderly prefer bigger screens with large font display and big keypads with more space in between and certainly not the more modern touch screen handsets. Though technology may improve the amount of content a device can provide, it is the user experience, which ultimately determines the impact of the appliance. The phone that opens the world to new ways of connecting must not be conceived as a mobile computer but as a unique space with its own implications and transformations. Young people, in their insatiable quest to embrace the new, have quickly adopted these devices into their lives in ways that emphasize the unique experience of the phone. Their uses and experiences are the key to understand the changed world of mobile connectivity. The main focus of this study is the implication of hand dimensions for ergonomically (Ergonomics-an applied science for designing and arranging things so that the users and the things interact more efficiently and safely) designed user-friendly mobile phone handsets.

Users' satisfaction is a main priority for many product designers. The success or failure of any product is heavily dependent on the end users' satisfaction. Literature review reveals that no study had investigated the effect of users' varying thumb sizes on texting satisfaction. Some users with large fingers have commented about the difficulty of using mobile phones to send text messages [1-3]. However, the very few reports which were based on SMS texting and users' satisfaction did not take the hand anthropometry (i.e. Hand/finger size) into consideration except those of [4]. Therefore, in order to obtain the optimum use of the mobile phones by any user, that is irrespective of gender or age, there is a need to understand what people in developing countries need from their mobile devices and how they can be applied in a way that positively impact their lives. Thus here an attempt is made to ergonomically design more user-friendly mobile handsets.

Material and Methods

The present study was conducted on 160 adult males (18 years or above) through ad hoc method of sampling from various educational institutes of Palampur region, Himachal Pradesh, India. All the subjects were asked for their voluntary consent and a friendly working environment was established between the subjects and the investigator. This made the data collection process easier.

While taking the hand measurements, subjects were made to sit on a stool or chair with hands kept on a horizontal platform. The following data were collected using a sliding caliper for the length and breadth measurements and a cloth tape to measure the circumferences.

Hand measurements

- Hand length (1): was measured as the straight distance from the midpoint of the stylion radiale (most distal point on the styliod process of the radius bone) and stylion ulnare (most

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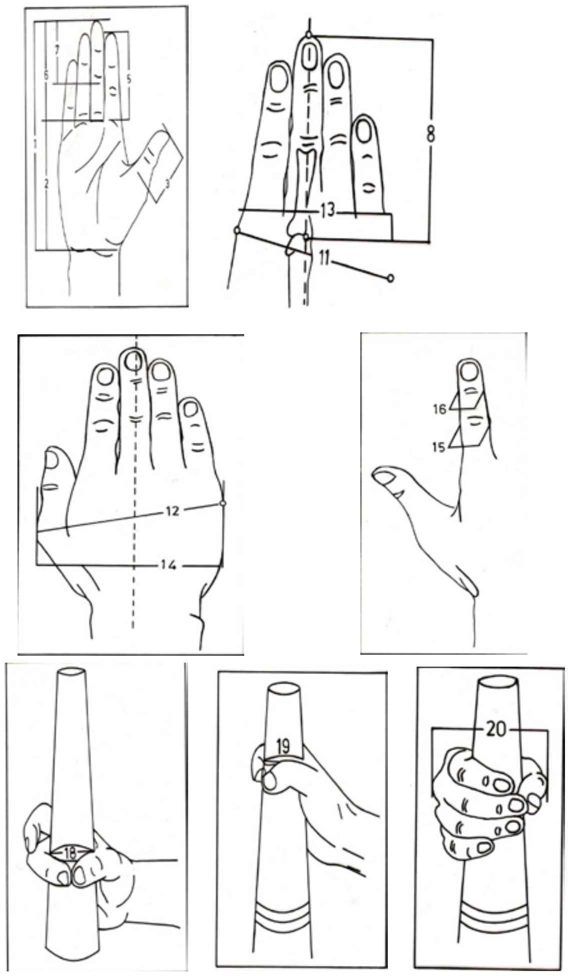
distal point on the styliod process of the ulna bone) to the most forwardly projecting point on the middle finger (Dactylion 3) (Figure 1).

- Palm length (2): The straight distance between the midpoint of wrist crease and the highest point on the head of the third metacarpal.
- Thumb length (3): was measured as the straight distance between the most projecting point on the tip of the distal phalanx of the first finger (thumb i.e., Dactylion 1) to the deepest point of the first metacarpo-proximal phalangeal joint of the thumb.
- Thumb circumference (4): It is the narrowest circumference of the thumb above the proximo-distal phalangeal joint of the thumb.
- Index finger length (5): It is the straight distance between the most distally projecting points of the tip of the distal phalanx of the second finger, that is, index finger, (Dactylion 2) to the deepest point of the metacarpo-proximal phalangeal joint of the second finger.
- Middle finger length (6): It is the straight distance between the most distally projecting points of the tip of the distal phalanx of the third finger (middle finger, that is, Dactylion 3) to the deepest point on the third metacarpo-proximal phalangeal joint of the third finger.
- Middle to distal phalanx length, middle finger (7): It is the straight distance between the landmarks Dactylion 3 to the deepest point on the proximo-middle phalangeal joint of the middle finger measured on the palmar surface.
- Total middle finger length, dorsal (8): It is the straight distance between the landmarks Dactylion 3 to the deepest point on the proximo-middle phalangeal joint of the middle finger measured on the dorsal surface.
- Bicondylar humerus (9): It gives the maximum distance between two most laterally placed points on the epicondyles of the humerus bone.
- Wrist breadth (10): It is the straight distance between the points, stylion radiale and stylion ulnare.
- Hand breadth (11): It is the straight distance between metacarpal radiale and metacarpal ulnare.
- Maximum hand breadth (12): It is the straight distance between metacarpal ulnare and the most projecting point on the first metacarpophalangeal joint.
- Hand breadth vertical (13): It is the straight, vertical distance between metacarpal ulnare and metacarpal radiale.
- Maximum hand breadth, vertical (14): It is the straight, vertical distance between metacarpal ulnare and the most projecting point on the 1st metacarpo-phalangeal joint.
- Index finger breadth, proximal (15): It is the straight distance between the most lateral and medial points on the proximo-medial phalangeal joint of the second finger (Index finger).
- Index finger breadth, distal (16): It is the straight distance between the most lateral and medial points on the medio-distal phalangeal joint of the second finger (Index finger).
- Hand thickness (17): It is the straight distance between the most superior points on the dorsal surface of the head of the second metacarpal to the most inferior point on the palmar surface (anterior) of the head of the 2nd metacarpal.
- Grip diameter, inside (18): It is the straight, inside diameter of the grip between the thumb (1st finger) and the 3rd finger.
- Grip diameter, inside, index finger (19): It is the straight, inside



1- Hand length
2- Palm length
3- Thumb length
4- Thumb circumference
5- Index finger length
6- Middle finger length
7- Middle to distal phalanx length, middle finger
8- Total middle finger length, dorsal
9- Bicondylar humerus
10- Wrist breadth
11- Hand breadth
12- Maximum hand breadth
13- Hand breadth vertical
14- Maximum hand breadth, vertical
15- Index finger breadth, proximal
16- Index finger breadth, distal
17- Hand thickness
18- Grip diameter, inside
19- Grip diameter, inside, index finger
20- Grip diameter, outside

Figure 1: Hand Measurements.

diameter of the grip between the index finger (2nd finger) and the thumb (1st finger).

- Grip diameter, outside (20): It is the straight distance between the most projecting point on the head of the 3rd metacarpal to the most projecting point on the proximo-distal joint of the thumb during the grip between the thumb and 3rd finger.

In addition to these hand measurements, keypad length, keypad breadth, key length, key breadth, horizontal spacing between keys, and vertical spacing between the keys were also measured with the help of digital Vernier Calliper for different mobile phones like Motorola KRZR, Nokia 3310, Nokia 5610, Motorola L6, Nokia 1110, Chinese phone, Samsung Sgh and Panasonic EB A 100.

Reliability

In surveys like the present one, it is essential to estimate the reliability of the measurements that would enhance the utility of the data. Reliability is a term applied to the comparison of independent measurements repeated on the same object within a short time interval. There are several types of error, usually called as personal error, instrument error, etc. A careful analysis of the repeated measurements reveals that these errors can be classified as 'random' and 'systematic' error. Recent literature, however, favors the terms 'within-observer replicates' and 'between observers replicates'. In the present study therefore, 'within-observer' reliability for anthropometric measurements are given in the terms of S_{meas}. Lesser S_{meas} values indicate high reliability levels.

In the present study the palpation of the landmarks and the techniques were practiced on about 160 males of different ages for sufficiently long time before starting the actual data collection and the reliability of the measure was checked. Fifteen subjects were selected randomly and measured twice within two hours. Each time the landmarks were palpated and marked afresh. The 'within-observer' S_{meas} for anthropometric measurements was calculated.

The S_{meas} for various hand measurements ranged between 0.14 ± 0.04 and 0.26 ± 0.02 mm. The same for the various key pad measurements-Keypad length, breadth, key length, breadth, horizontal and vertical spacing between keys ranged between 0.14 ± 0.02 and 0.24 ± 0.02.

Statistical analysis

The analysis and the interpretation of the numerical data were done using the Statistical Product and Service Solution (SPSS). Paired *T*-test, Factor analysis using principal component method and varimax rotation, and Pearson Correlation methods were applied.

Results

Factor analysis

T-test was applied to find out any significant differences in the dimensions of both the hands. Significant difference at 1% level was found in hand length, thus for the hand measurements of the right and left hand, the factor analysis was done separately.

Since the goal of applying factor analysis is to examine the "structure" of the relationship among the variables, not to see how they relate to other variables, thus, no distinction was made between the independent and dependent variables and all are treated equally. For the factor analysis to be appropriate, the variables must be correlated. The correlation matrix, constructed from the data, showed relatively high correlations among the variables in both the hands. Besides, the approximate chi-square statistic was significant at 0.05 level and value of KMO statistic was also larger than 0.5, therefore, factor analysis was considered as an appropriate technique for analyzing the correlation matrix. The eigen values for the factors were, as expected, in the decreasing order of magnitude. While determining factors based on eigen values, only factors greater than 1.0 were retained; the other factors were not included in the model.

Right hand

5 dominant factors emerged explaining 72% of the total variance (Table 1):

- Factor 1 is dominated by hand length; middle finger length; index finger length; middle finger length, dorsal; middle and distal phalanx length; middle finger; palm length explaining 25% of variance.
- Factor 2 is dominated by maximum hand breadth; vertical; maximum hand breadth; hand breadth explaining 14% of variance.
- Factor 3 is dominated by grip diameter; inside index finger; and grip diameter, inside explaining 12% of variance.
- Factor 4 is dominated by index finger breadth, distal; and index finger breadth, proximal explaining 11% of variance.
- Factor 5 is dominated by wrist breadth; and hand breadth, vertical explaining 9% of variance.

Left hand

Dominant factors emerged explaining 63% of the variance (Table 2):

- Factor 1 is dominated by the middle finger length; hand length; middle finger length, dorsal; middle and distal phalanx length, middle finger; index finger length; palm length; and thumb length explaining 28% of the variance.

	Component				
	1	2	3	4	5
Hand length	.895				
Middle finger length	.880				
Index finger length	.829				
Middle finger length, dorsal	.783				
2 and 3 phalanx length, middle finger	.776				
Palm length	.715				
Thumb length					
Bicondylarhumerus					
Maximum hand breadth, vertical		.757			
Maximum hand breadth		.746			
Hand breadth		.704			
Grip diameter, outside					
Grip diameter, inside, index finger			.929		
Grip diameter, inside			.926		
Index finger breadth, distal				.814	
Index finger breadth, proximal				.792	
Hand thickness					
Wrist breadth					.716
Hand breadth, vertical					.627
Circumference of thumb r					

[Only factor loadings greater than 0.6 are shown]

Table 1: Rotated Component Matrix (Right hand).

	Component		
	1	2	3
middle finger length	.911		
hand length	.874		
middle finger length, dorsal	.842		
2 and 3 phalanx length, middle finger	.837		
index finger length	.816		
palm length	.658		
thumb length	.653		
index finger breadth, distal		.781	
index finger breadth, proximal		.778	
circumference of thumb		.762	
maximum hand breadth, vertical		.632	
hand breadth, vertical		.619	
bicondylarhumerus			
wrist breadth			
hand breadth			
hand thickness			
maximum hand breadth			
grip diameter, inside, index finger			.911
grip diameter, inside			.903
grip diamter, outside			

[Only factor loadings greater than 0.6 are shown]

Table 2: Rotated Component Matrix (Left hand).

- Factor 2 is dominated by index finger breadth, distal; index finger breadth, proximal; circumference of the thumb; maximum hand breadth, vertical; and hand breadth, vertical explaining 20% of the variance.
- Factor 3 is dominated by grip diameter, inside index finger; and grip diameter, inside explaining 15% of the variance.

Among the factors, four main factors i.e., Hand length (HL), Hand breadth (HB), Thumb length (TL), and Thumb circumference (TC) were selected for further study as these were found to explain maximum variation in hand grip. These four factors were then correlated with various mobile phone keypad dimensions such as Keypad length (KPL), keypad breadth (KPB), Key length (KL), Key breadth (KB), Horizontal spacing between keys (HS), and Vertical spacing between the keys (VS). Following results were found out (Tables 3-8).

Discussion

With the erect posture human hands became available for greater use of tools. Besides, the anatomical reconstruction of the human hand during the course of evolution with a fully opposable, muscular and mobile, thumb with long, straightened fingers enabled the *Homo sapiens* to employ various complicated tools with greater ease compared to the other primates. One such modern, ubiquitous tool without which the man today cannot exist is the mobile phone. Even people who live below poverty line own one. Like their choice of different types of handsets –clamshell, candy bar slider, touch screen etc., people display different types of grip when they are using the mobile handsets

Even though the basic human grips are unique, that is, humans have the capability to grip a tool in two different ways [5].

- The Power Grip – tightly grasping an object in a closed fist between the palm and fingers.
- The Precision Grip–grasping an object between the thumb and the distal phalanges of the fingers-interestingly, the human hand that grips the mobile phones exhibits a much wider variation. Among these the main categories are:

1. Firm grip – It is also a type of power grip in which, the fingers wrap around the handset, all the phalanges are involved.
2. Soft grip – It is a special case of precision grip in which the hand holds the handset only with the distal phalanges of the fingers, thus creating a gap between the palm and the handset.
3. Firm-push grip – In which, the phalanges are aligned on the same plane of the palm, pushing the handset to the cheek/ear.
4. Soft-push grip – In this only the distal phalanges of II or V or any two of them push the mobile phone to the cheek/ear while keeping the palm away.

Among these main categories there exists a variety of internal variations brought about by the relative position of the fingers with respect to the hand set that result in a large number of secondary grip positions. Different mobile phones are held in different ways while talking. The shape of the handset, that is, a Candy bar, mainly influences the grip position and clamshell handsets are expected to be held in different ways. Besides it seems that mainly it is the size rather that the shape that affects the grip position. Moreover in this study same factors affected both the hands either left or right. Since hand length; palm length; index finger length; middle finger length; middle finger length, dorsal; middle and distal phalanx length, middle finger; hand breadth; maximum hand breadth, vertical; maximum hand

		KPL
HL	Pearson Correlation Sig. (2-tailed)	.226 .591*
HB	Pearson Correlation Sig. (2-tailed)	.104 .806*
TL	Pearson Correlation Sig. (2-tailed)	-.343 .405
TC	Pearson Correlation Sig. (2-tailed)	.218 .604*

*Significant at p > 0.5

Table 3: Correlation between KPL and HL, HB, TL, TC.

		KPB
HL	Pearson Correlation Sig. (2-tailed)	-.477 .232
HB	Pearson Correlation Sig. (2-tailed)	-.399 .328
TL	Pearson Correlation Sig. (2-tailed)	-.515 .192
TC	Pearson Correlation Sig. (2-tailed)	.412 .311*

*Significant at p > 0.5

Table 4: Correlation between KPB and HL, HB, TL, TC.

		KL
HL	Pearson Correlation Sig. (2-tailed)	.062 .884*
HB	Pearson Correlation Sig. (2-tailed)	-.239 .568
TL	Pearson Correlation Sig. (2-tailed)	.175 .678*
TC	Pearson Correlation Sig. (2-tailed)	-.237 .573

*Significant at p > 0.5

Table 5: Correlation between KL and HL, HB, TL, TC.

		KB
HL	Pearson Correlation Sig. (2-tailed)	.074 .862*
HB	Pearson Correlation Sig. (2-tailed)	.032 .941*
TL	Pearson Correlation Sig. (2-tailed)	.296 .477*
TC	Pearson Correlation Sig. (2-tailed)	-.053 .900

*Significant at p > 0.5

Table 6: Correlation between KB and HL, HB, TL, TC.

		HS
HL	Pearson Correlation Sig. (2-tailed)	.108 .838*
HB	Pearson Correlation Sig. (2-tailed)	-.114 .829
TL	Pearson Correlation Sig. (2-tailed)	-.324 .531
TC	Pearson Correlation Sig. (2-tailed)	.415 .413*

*Significant at p > 0.5

Table 7: Correlation between HS and HL, HB, TL, TC.

		VS
HL	Pearson Correlation Sig. (2-tailed)	.023 .966*
HB	Pearson Correlation Sig. (2-tailed)	-.145 .784
TL	Pearson Correlation Sig. (2-tailed)	-.385 .451
TC	Pearson Correlation Sig. (2-tailed)	.461 .358*

*Significant at p > 0.5

Table 8: Correlation between VS and HL, HB, TL, TC.

breadth; thumb length; and thumb circumference were found to affect hand grip so manufactures should keep it in mind while designing the mobile phones.

Hand dimensions do affect the users' satisfaction especially on key size, space between keys and layout. Therefore, hand differences in both the sexes, and those among the elderly people should also be considered. Besides, attempt should also be made on the basis of categorization of hand length, and handbreadth into various subcategories (small, medium, and large). Regression equation can then be derived with various mobile phone dimensions and then by comparing the estimated values with those of observed, it can be seen which hand dimensions are well suitable for which kind of mobile phones.

All these factors are to be considered for designing the mobile handsets/ customized mobile handsets that cater to a particular group of users. This would encourage more users to switch over to SMS as users satisfaction results in usage [6]. This study provides insight to the relationship between hand anthropometry, handgrips, keypad design, and SMS satisfaction of the mobile phone users. Thus providing a better understanding of mobile phone designing problems related to hand grips, and SMS plus the important keypad design factors that affect the users' satisfaction.

Mobile phone keypads

Since the mobile phones keyboards were originally designed for dialing numbers thus making text messaging difficult. The standard ISO mobile phone has only 12 keys ('0'-'9', '#' and '*') to input the entire alphabets, punctuations and numerical characters (Figure 2). Each physical key is therefore overloaded with three or four alphabetical characters; for example, the digit '9' is used for 'W', 'X', 'Y' and 'Z'. Consequently, this requires the users to make multiple key presses in order to make their intended selection. Although there are numerous published reports however, almost all of them attempt to tackle keypad design problems by focusing on the text input mechanism [7-10,4]. In fastap keypad, 52 independent keys are fit into an area same size as the standard ISO keypad. Though the performance of fastap keypad is much improved over the earlier ISO one, the tiny key sizes may probably pose problem to the users besides the additional cost [11-13,3]. Elderly people found the keys are placed too close to each other [14].

It seems that gender and hand size significantly affect the subsets' satisfaction with regards to mobile phone design factors. Miniaturization is the trend in designing the mobile these days. Females as they generally have smaller hands/thumbs are more satisfied with key size than males. Thus, when mobile phones get smaller in size, key size also is forced to shrink-this becomes one of the major problems for mobile phone users with large hand size and thumbs as making multiple key presses without mistakes possess a difficult task-especially for males and the elderly [1,3,14] as is the case in the present study (Table 5).

Simplicity of the key, shape and texture

According to Yun et al. [15], females emphasize on aesthetic values compared to males, while men prefer clearness of menu items and softness of bell sound. While the respondents in the present study preferred not to have multitap system, squarish keys, and about texture nobody bothered much.

Overall keypad design satisfaction

Individuals and the females with normally small sized hand and thumb are satisfied with the overall keypad design whereas males with larger hand dimensions found it much easier to ring than messaging [2,4]. This finding is consistent with the results shown in the tables 3 and 4.

However, the main flaw in the previous studies [1,3,14] is that their results were based on the users' reports. None of them took the anthropometric details of the hand-wrist. Even though many of the mobile sets possess the standard 12-key layout (Figure 2), due to the small size of the mobile phones, the users, it seems, are familiar with the layout. Nevertheless, the mobile phone users felt that having more keys would increase their efficiency in messaging by reducing key overloading which was the main obstacle in text entry in the mobile phones

Figure 2: Mobile phone keypads.

[14,7,13,3]. The 3G mobiles have more keys to increase their efficiency. However, users in these studies as in the present one were quick to point out that the increase in number of keys should not increase the hand set size over the look. Similarly, keypad layout was one of the usability issues in using SMS [1,3]. Their satisfaction is also critically affected by harmoniousness that is, a feeling that the components of a product are well matched in harmony [15]. In mobile handset, the arrangement of a display and its relevant buttons may affect perceived harmoniousness. In other words well-arranged keys make a more user-friendly mobile handset, i.e. the possibility of hitting wrong keys can be reduced by texting especially by males who have larger hands and thumbs than the females.

Space between keys

Majority of males and the elderly reported that they found messaging cumbersome as while composing the message they tend to press the wrong keys mainly with mobile handsets with less space between keys especially in a rapidly changing physical environment [13-16]. Thus makes the users with larger hands and thumbs to make phone calls than to send SMS as also displayed by the present study.

Recommendations

- Since hand length; palm length; index finger length; middle finger length; middle finger length, dorsal; middle and distal phalanx length; middle finger; hand breadth; maximum hand breadth, vertical; maximum hand breadth; thumb length; and thumb circumference were found to affect hand grip so manufactures should keep it mind while designing the mobile phones.
- Hand dimensions do affect the users' satisfaction especially on key size, space between keys and layout.
- All these factors are to be considered for designing the mobile handsets customized mobile handsets that cater to a particular group of users. This would encourage more users to switch over to SMS as users satisfaction results in usage [17].
- This study provides insight to the relationship between hand anthropometry, hand grip, keypad design, and SMS satisfaction of the mobile phone users. Thus providing a better understanding of mobile phone designing problems related to hand grips, and SMS plus the important keypad design factors that affect the users' satisfaction.
- It is recommended that further research-laboratory-usability experiments may be followed.
- For the use of elderly people screen should be large enough so that visibility is clear with larger keypads having more space between the keys.
- Manufacturers must follow the exposure limit for radiation as Radio Frequency Radion (RFR) from a mobile held against the ear will heat the brain even though the exposure limit for radiation from mobiles is very low.
- Hand differences in both the sexes, and those among the elderly people can also be considered.
- Attempt can also be made on the basis of categorization of hand length, and hand breadth into various subcategories (small, medium, and large). Regression equation can then be derived with various mobile phone dimensions and then by comparing the estimated values with those of observed, it can be seen which hand dimensions are well suitable for which kind of mobile phones.
- It would be interesting to see if these hand-size variations have any effect on the recently launched 3G (Third Generation) mobile phones.

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