Automated Neoclassical Vertical Canon Validation in Human Faces with Machine Learning

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Abstract: The proportions defined by the neoclassical canons for face evaluation were developed by artists and anatomists in the 17th and 18th centuries. These proportions are used as a reference for planning facial or dental reconstruction treatments. However, the assumption that the face is divided vertically into three equal thirds, which was adopted a long time ago, has not been verified yet. We used photos freely available online, annotated them with anthropometric landmarks using machine learning, and verified this hypothesis. Our results indicate that the vertical dimensions of the face are not always divided equally into thirds. Thus, this vertical canon should be used with caution in cosmetic, plastic, or dental surgeries, and reconstruction procedures.

1 INTRODUCTION

The face is one of the most important factors affecting the physical appearance of a person. Different facial proportions can be used for measuring the facial attractiveness, for recommending hairstyles, fashion jewelry, eyeglasses, etc. The measurement of facial attractiveness is also applicable in cosmetics, orthodontics and plastic surgery. Dental practitioners take into consideration the different facial proportions in order to create a denture of suitable shape, size, and position.

The neoclassical canons used for proportional evaluation of the face were developed in the 17th and 18th centuries. These canons were based on the assumption that certain fixed ratios existed between different parts of a human face. They are still used to define the proportions between various areas of the head and face. One of these eight defined neoclassical canons is the vertical canon, which states that the face is divided into three equal sections. The first section is from the top of the forehead (Trichion), to the bridge of the nose (Glabella), as shown in Figure 1, the second section is from the bridge of the nose to the base of the nose (Subnasale), and the third section is from base of the nose to the chin (Menton). Trichion, Glabella, Subnasale and Menton are the anthropometric landmarks that are identified before taking the measurements of the facial thirds. The vertical canon is widely used in facial surgeries and dental reconstruction procedures.

Farkas et al. (1985) first investigated the applicability of the neoclassical facial canons in young North American Caucasian adults. Following this, the canons were also validated on several other population groups including Nigerians, African-Americans, Turkish, Vietnamese, Thai, and Chinese individuals. These studies were performed by adopting the standard anthropometric methods and the measurements were obtained using anthropometric tools like millimetric compass, sliding calipers, etc. Some studies have used images pre-annotated with the anthropometric landmarks.

Missing teeth with age causes a person's face to collapse. While fixing the patient's teeth, it is also important to consider restoring the patient's facial shape. With a collapsed face, only the bottom one third of the face, i.e., from Subnasale to Menton is affected and needs to be restored. This facial restoration also needs some reference for comparing the facial shape proportions to convert the collapsed face into normal facial shape. Inclusion and evaluation of facial aesthetics is important while planning for facial or den-

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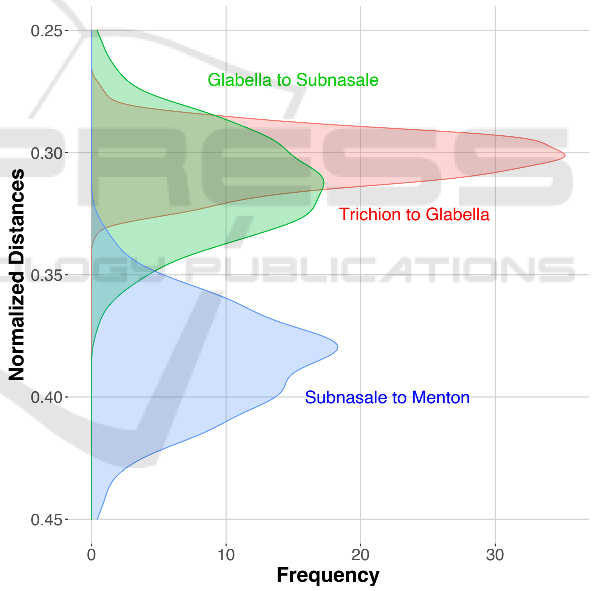
(a) The neoclassical vertical canon states that the face is divided into three equal thirds.

(b) To test this hypothesis we used the Dlib-81 library to automatically place facial landmarks on an image.

(c) Out of the landmarks generated by the Dlib-81 library we used the ten circled landmarks to place the four lines.



(d) The density distributions of the three distances using annotated images from LFW, MUCT, and CUHK datasets seem to invalidate this hypothesis.

Figure 1: Facial landmarks are used to automatically place the lines for Trichion, Glabella, Subnasale, and Menton. These lines were used in one of the neoclassical canons, the vertical canon, to surmise that each face is divided into three equal sections. However, evidence shows that these distances are not equal.

tal reconstruction treatment. Many clinical textbooks and journal articles recommend to use these neoclassical canons for evaluating the aesthetics. However, before blindly applying these recommended neoclassical formulae, it is important to validate them. With the advancements in technology, it is no longer required to use the traditional anthropometric tools to take measurements from the human face. We can use machine learning to train a model to automatically identify the different anthropometric landmarks of the human face and thus avoid the need for direct contact with patients. The objective of this study is to verify the vertical canon by using machine learning to eliminate the need to take the measurements manually using different anthropometric tools.

All the canon validation methods that have been proposed have used different physical instruments (Le et al., 2002; Bozkir et al., 2004; Al-Sebaei, 2015; Eboh, 2019) and software applications for taking measurements of the face (Burusapat and Lekdaeng, 2019). Some of the proposed techniques have used a ready-made database that had images with the anthropometric landmarks annotated (Schmid et al., 2008; Pavlic et al., 2017). However, none of the techniques have used automated tools for getting the measurements and validating this canon. These techniques are discussed in Section 4.

Our proposed method used large volume of photos available online, annotated them with automated tools, and verified this hypothesis. We have performed the automatic validation of the vertical canon by annotating the images from three freely available image databases using machine learning. By using the proposed method, one can validate the vertical canon automatically without the need to use traditional anthropometric tools or instruments directly on the patient.

2 MATERIALS AND METHODS

We tested the applicability of the vertical neoclassical canon on the facial images collected from three freely available datasets: Labeled Faces in the Wild (LFW) face database (Huang et al., 2007), the Milborrow / University of Cape Town (MUCT) face database (Milborrow et al., 2010), and the Chinese University of Hong Kong student database (Wang and Tang, 2009). The LFW is a database of face photographs designed for studying the problem of unconstrained face recognition. The data set contains 13,233 facial images of 5749 individuals collected from the web. All the images in the LFW database have a resolution of 250 × 250 pixels. The MUCT face database consists of 3,755 facial images of 276 individuals. The individual were sampled from students, parents attending graduation ceremonies, high school teachers attending a conference, and employees of the university at the University Of Cape Town campus in December 2008. This diverse population includes a wide range of subjects, with approximately equal numbers of males and females, and a cross section of ages and races. All the images in the MUCT database have a resolution of 480 × 640 pixels. The CUHK database is for research on face sketch synthesis and face sketch recognition, and consists of 188 facial images of 188 individuals. All the images in the CUHK database have a resolution of 1024 × 768 pixels. All the facial images were not labeled with any anthropometric landmarks.

Our proposed workflow had the following steps:

1. Annotation: The first step was to annotate these images with facial anthropometric landmarks. We initially evaluated the Dlib's 68-point facial landmark detector (King, 2009), the most popular facial landmark detector. It can find 68 different facial landmark points including chin and jaw line, eyebrows, nose, eyes and lips. In our preliminary work we determined that this library does not provide facial landmarks for the forehead. Therefore, we used an extended version of this library, 81 Facial Landmarks Shape Predictor, which provides 13 additional landmarks that delineate the forehead. Not all the landmarks generated are needed to get the measurements of the thirds of the face. Out of all the 81 landmarks, we used only the following landmarks, as shown in Figure 1c:

- 69 and 72, for the left- and right-forehead, respectively. These landmarks were used for the placement of the Trichion line.
- 77, 17, 26, and 78, for the left-temple, left-exterior eyebrow, right-exterior eyebrow, and right-temple, respectively. These landmarks were used for the placement of the Glabella line. This is the only line for which we used four landmarks, since none of the 81 landmarks are placed at the position for the bridge of the nose. Therefore, we used the mid-vertical distance between landmarks 77 and 17, along with the mid-vertical distance between landmarks 26 and 78, as the anchors for the Glabella line.
- 31 and 35, for the left- and right-base of the nose, respectively. These landmarks were used for the Subnasale line.
- 7 and 9, for the left- and right-side of the chin, respectively. These landmarks were used for the Menton line.

2. Assess the Annotation: The second step was to visually inspect the placement of the four lines mentioned above, on all the images from the three datasets. During this manual inspection we noticed that the predictor placed the landmarks in the correct positions in images that had eyeglasses, beard, bald heads, hats, as well as for people of different age groups and races, and to different background colors and patterns. However, some of the lines were not correctly placed for images that did not have a front profile view. For some of these images, the 81 Facial Landmarks Shape Predictor misplaced some of the landmarks, which led to the incorrect placement of the Trichion, Glabella, Subnasale and Menton lines, as shown in Figure 2.

3. Select Images: Therefore, to get a correct and unbiased measurement of the thirds of the face, in the third step we planned to select about 500 images, that had correctly positioned landmarks. We identified 464 images from the LFW dataset, 86 images from the MUCT dataset, and 29 images from the CUHK dataset (for a total of 579 images), that had the correct automatic placement of the four lines.

4. Calculate Distances: We used these images, in the fourth step to calculate the three facial distances: between Trichion and Glabella, between Glabella and Subnasale, and between Subnasale and Menton. The initial distance measurements were taken in number of vertical pixels between each two lines. Since we used images from all the three image databases, we had to take into consideration the fact that the images were provided with different resolutions. Therefore, we performed normalization of all the three distance values using Equation 1.

$$d'_i = \frac{d_i}{\sum_{j=1}^{3} d_j} \tag{1}$$

where d'_i is the normalized distance of d_i, and d_j is one of the three distances.

5. Plot Density Distributions of These Distances: In the final step we used these normalized distances to generate density plots for the three distances. These are shown in Figure 1d for the 579 combined images, and in Figures 3b, 3d, and 3f, for the 464 images from the LFW database, the 86 images from the MUCT database, and the 29 images from the CUHK database, respectively.

3 RESULTS AND DISCUSSION

Figure 1d shows the distribution of the three distances across the selected images from the three databases. These density plots show that the forehead, the distance between Trichion and Glabella, varies between about a fourth and a third of the face, with the mean around 30%. The nose, between Glabella and Subnasale, has a wider distribution, with length values between about 25% and 38% of the vertical length of the face, and a mean closer to one third. The mouth, between Subnasale and Menton, seems to be the longest of the three distances, with lengths between about 32% and 45% of the vertical length of the face, and a mean of about 38%.

One of the confounding factors of these variations is the resolution of the images in our analysis. For images with lower resolution the misplacement of the landmarks has a bigger influence of the distances, since 1 or 2 extra pixels could increase or decrease a distance by about 4%. For images with higher resolution such a misplacement would have a lesser impact on the normalized distances. To evaluate this impact we plotted the density distributions for each dataset separately, as shown in Figure 3. While there doesn't seem to be significant differences in the lengths of forehead and nose, across the three datasets, the length of the mouth, the distance between Subnasale and Menton, seems to have more variance for images with lower resolution, than for images with higher resolution.

One thing that is common across these density plots is the fact that these distances are not equal, with about 1/3 for forehead, 1/3 for nose, and 1/3 for mouth, as stated in the neoclassical canon, but rather that they have a range of values, with longer length for mouth than for nose and forehead. Thus, they suggest that this canon is not valid, and therefore it should be used with caution in cosmetic, plastic, or dental surgeries, and reconstruction procedures.

This analysis would require further evaluation, as many groups were not well represented in these datasets. For example, there are very few children, very few people over the age of 80, and a relatively small proportion of women. In addition, many ethnicities have very minor representation or none at all. In addition to creating a new dataset that has a wider representation, we also recommend collecting metadata about the images, which should include the details about each individual, such as age, race, etc., as well as whether they have all teeth or if they have dentures (which is difficult to determine from these images). Furthermore, the images should include a side profile view for each person, in addition to the frontal view.

Another alternative to a new image database, that is worth exploring, is to collect and annotate three-dimensional scans. These have the potential to enable better localization of the four lines, as with two-dimensional front views it is difficult to determine the position of the Trichion and Glabella.

4 RELATED WORK

Bozkir et al. (2004) have performed the validation of vertical and horizontal neoclassical facial canons in Turkish young adults. They used a millimetric compass to take the measurements manually. The mea-

Figure 2: Incorrect placement of landmarks on some images from the MUCT database due to shift in face positions. The left and middle images have the Glabella line misplaced, and the right image has the Glabella and Menton lines misplaced.

surements were taken manually twice by the same investigators by filling out a form for recording the values. Based on their measurements, it was observed that only one male face had an equally divided facial profile. It was observed that the neoclassical canons were not valid in the majority of the population and the canons vary among races and also countries.

Al-Sebaei (2015) have performed the validation of the vertical canon, the orbital canon and the orbitonasal canon in young adults originating from the Arabian Peninsula. They measured the neoclassical canon using a caliper and analyzed the measurements using Student's t-test, general linear modeling, and pairwise comparison of means. The results indicated that all the three canons had variations in measurements. It was found out that the lower and upper thirds were longer than the middle thirds, the intercanthal distance was wider than eye fissure length and the nasal width was wider than the intercanthal distance.

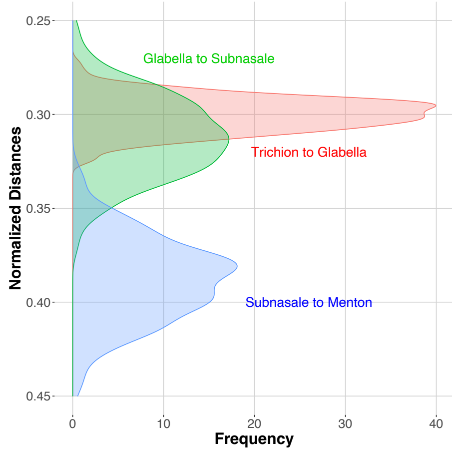
Eboh (2019) has performed a study of young adults in South-South Nigerian Ethnic Groups, Izon and Urhobo, to determine if there is a variation in length among the upper, middle and lower thirds of the face. The measurements of the thirds were taken in millimeters by using a sliding caliper. They performed data analysis with SPSS 23 by using descriptive and inferential statistics. In conclusion, it was found out that the three thirds of the face varied in lengths. The mean lengths of the upper and lower thirds were significantly longer in the Izon than the Urhobo, while the mean height of the middle third was significantly longer in the Urhobo than the Izon. The mean height of the male lower third was significantly longer in the Izon than the Urhobo, while Urhobo females had significant longer middle third than the Izon.

Schmid et al. (2008) have developed a model to predict the attractiveness of the face based on neoclassical canons, symmetry and golden ratios. They used the feature point database that consists of the locations of the feature points for the faces from the FERET database and the faces of famous people. Neoclassical canons were one of the many predictors of attractiveness. One of these neoclassical canons used was the vertical canon where forehead height = nose length = lower face height. From the experiment results, it was found out that the vertical canon had a significant relationship with attractiveness. It was also found out that the attractiveness scores decreased significantly as the proportions of the face deviated from the proportions defined by the canons.

Pavlic et al. (2017) have explored the presence of neoclassical canons of facial beauty among young people in Croatia and checked for any possible psychosocial repercussions occurring in those who demonstrate deviations in relation to the canons. Nine neoclassical canons of facial beauty were analyzed on a sample of 249 people with face and profile photographs taken in Natural Head Position. Calculations were performed in the statistical software MedCalc 14.8.1 and based on previously published data. One of the 9 canons analyzed is the three portion facial profile canon where trichion – nasion (tr – n) = nasion – subnasale (n – sn) = subnasale – gnathion (sn – gn). All analyses were performed in the software AudaxCeph. Significant deviations from neoclassical facial beauty canons were found in 55–65% of adolescents and young adults and gender and age showed no relation to deviations. Most of the deviations from canons that affected the quality of life were the ones related to proportions of facial thirds.

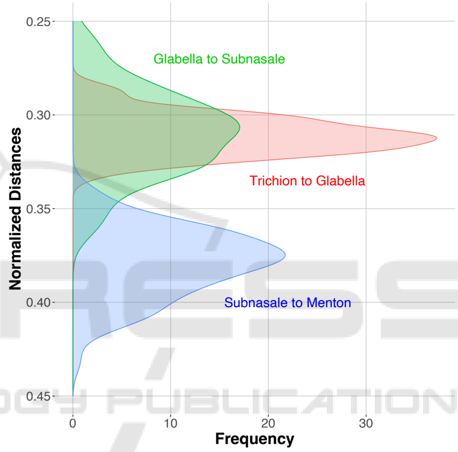
Le et al. (2002) have performed the validation of

(a) Sample image from the LFW dataset. The images in this dataset have a size of 250 × 250 pixels.

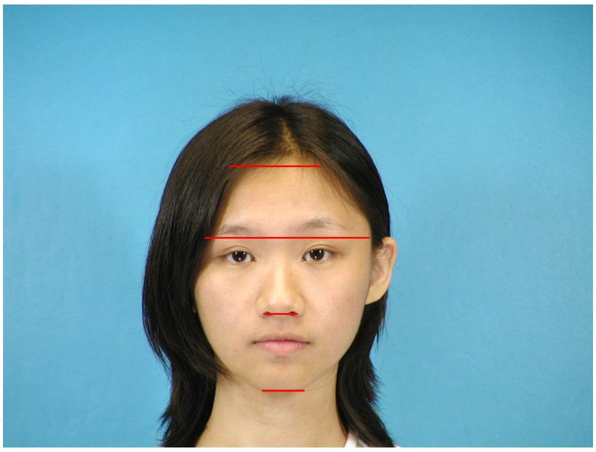


(b) The density distributions of the three distances for the 464 images used from the LFW dataset.

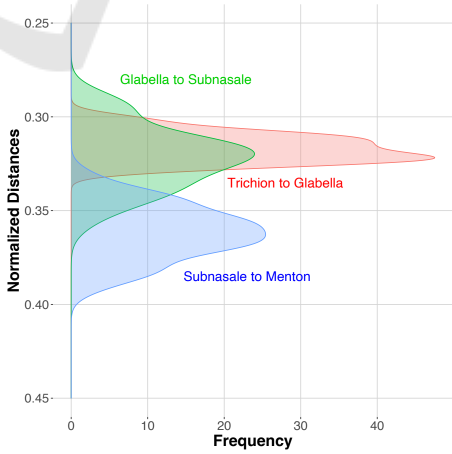
(c) Sample image from the MUCT dataset. The images in this dataset have a size of 480 × 640 pixels.



(d) The density distributions of the three distances for the 86 images used from the MUCT dataset.



(e) Sample image from the CUHK dataset. The images in this dataset have a size of 1024 × 768 pixels.



(f) The density distributions of the three distances for the 29 images used from the CUHK dataset.

Figure 3: Examples of images used in this analysis, shown to scale, from the following datasets: LFW, MUCT, and CUHK, along with their corresponding distance distributions. The distributions for each dataset indicate that the neoclassical vertical cannon is not valid.

six neoclassical canons among healthy young adult Chinese, Vietnamese and Thais by taking nine projective linear measurements. The nine projective linear measurements were taken by the authors by using standard anthropometric methods. These nine measurements corresponded to six neoclassical facial canons. It was found out that in neither Asian nor Caucasian subjects were the three sections of the facial profile equal.

Burusapat and Lekdaeng (2019) have performed a comparative study among sixteen Miss Universe, sixteen Miss Universe Thailand, neoclassical canons and facial golden ratios to find out the most beautiful facial proportion in the 21st century by using twenty-six facial proportion points. Acrobat Reader was used to measure the distances and angles and the data was recorded in Microsoft Excel to compare the facial proportions. From the results, it was found out that the three-section proportion was longer in Miss Universe Thailand than in Miss Universe group.

Amirkhanov et al. (2020) have proposed a solution for integrating aesthetics analytics into the functional workflow of dental technicians. They have presented a teeth pose estimation technique that can generate denture previews and visualizations that helps the dental technicians for designing the denture by considering the aesthetics and choosing the most aesthetically fitting preset from a library of dentures, in identifying the suitable denture size, and in adjusting the denture position. In one of the use cases that are demonstrated in this paper, it is stated that the dental technician uses the facial and dental proportions to identify the correspondence between the denture and the face which means that it is important to have the facial proportions correct for the denture to fit well on a patient.

5 CONCLUSIONS

The neoclassical canons were used to define the different proportions between various areas of the head and the face. These facial canons have been recommended in various textbooks about orthodontics, prosthodontics, plastic and dental reconstructive surgeries for planning the treatment procedure. We tested the hypothesis of the face being vertically divided equally into thirds using machine learning. Our results indicate that the vertical dimensions of the face are not always divided equally into thirds. Thus, this vertical canon should be used with caution in cosmetic, plastic or dental surgeries or any reconstruction procedures.

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