Computers in Biology and Medicine 76 (2016) 168–172

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Automatic counting of fungiform papillae by shape using cross-correlation

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ARTICLE INFO

Article history:
Received 21 August 2015
Received in revised form
7 July 2016
Accepted 8 July 2016

Keywords:
Machine vision
Pattern analysis
Fungiform papillae
Automated counting

ABSTRACT

The determination of the number of fungiform papillae (FP) on the human tongue is important for taste sensitivity studies. Most of the time, the counting of the FP is done manually. In this paper we propose a novel algorithm to count the FP using shape characteristics measured by cross-correlation. The accuracy of the algorithm is evaluated by counting the FP manually on the same images and then doing a statistical analysis. A Poisson regression model is fitted using maximum likelihood. The result is that the algorithm counts are very similar to the human experts. Another advantage of the algorithm is its facility of use, velocity and that it can work on a plain tongue image, without the need to stain the tongue as is usual in manual counting.

1. Introduction

Sensory evaluation is a quantitative science [1], which comprises a number of methodologies to stimulate sight, smell, touch, taste and hearing [2–4]. It measures human responses to food, analyzes and interprets the results, minimizing the bias that can exercise the brain and other identity information that could influence consumer perception [5–8].

The tongue is a bundle of striated muscles on the floor of the mouth, with numerous papillae and taste buds [8]. The papillae are a kind of fleshy bulbs of several millimeters diameter [4]. They are classified into circumvallate or caliciform, foliate, filiform and fungiform. The latter are mushroom shaped [14], containing about 5 taste buds [9,10,20,21].

The amount of fungiform papillae has also been used to provide information about the function of taste, since it has been found that the density of papillae decreases in people with neural damage or after following some medications [14,22]. In addition, it has been shown that the number of papillae and taste buds is correlated with the supra threshold sensitivity of taste [23], providing evidence that the anatomical differences between individuals are determinant [2].

In fact, on this basis, individuals have been classified according to the fungiform papillae density as supertasters, tasters and non-tasters [20]. Several researchers have shown that those who have a greater number of fungiform papillae perceive more intensely bitter tastes, sweet, salty, fat and pain sensations [21,24–27]. They also tend to consume fewer fruits, vegetables and drinks with bitter tastes. Because of this, the sensory sensitivity has been linked to the BMI and to the risk of diseases such as cancer, diabetes and alcoholism [28–34].

So the amount of fungiform papillae could be used as an indicator of sensory acuity to select members of evaluation panels for the food industry, besides being used as a preliminary test to diagnose some types of neurological damage [23] and to prevent suffering from diseases related to eating habits.

On the other hand, artificial vision is a branch of artificial intelligence, which aims to mathematically model the processes of visual perception in living beings, creating programs to simulate these visual capabilities, including learning and the ability to infer and perform actions based on visual cues, through a computer [11,12]. The machine vision process receives as input one or more sequences of images, taken from different angles by one or more cameras and from this volume of visual information, an interpretation of the environment is obtained [12].

For the purpose of counting the fungiform papillae, non-invasive methods such as video microscopes and digital cameras

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http://dx.doi.org/10.1016/j.compbiomed.2016.07.002
0010-4825/

have been used, getting similar results with both. However, the use of the video microscope is limited to the laboratory, and requires 30 to 60 min to obtain high quality images of an individual [13]. On the other hand, digital cameras are faster, portable, flexible and of lower cost [13,14], but when the images have been taken, an expert has to count the fungiform papillae manually, one by one.

Even though there are studies that reported on the behavior of people towards the sensitivities of bitter compounds and determined the density and size of the fungiform papillae among Asian and Caucasian people through manual counting [15], there are no reports of any software or algorithms that perform FP counting using digital images. That is why we propose an algorithm that works on digital images to automatically count FP, obtaining significant savings in time and cost.

2. Materials and methods

53 persons were chosen based on one socio-demographic survey, 31 women and 22 men, aged 18 to 56 years, students and professors of the School of Nutrition, from the University of Veracruz in Xalapa, Veracruz. All the participants gave verbal consent to participate in the study and nobody was harmed. Our study complies with the Declaration of Helsinki for Medical Research involving Human Subjects. Several images of their tongues were taken using a digital camera. Then these images were analyzed and the FP were counted manually and through a machine vision algorithm described below. In this study only one human operator manually counted the FP in all the images.

2.1. Machine vision algorithm

An image processing algorithm was developed. It is able to determine the number of fungiform papillae present in an area of the tongue by using cross-correlation between a digital image of the tongue and a prototype papilla. Three to six digital images of the tongue of each person were taken. From these, the best quality image was selected by considering the focus, brightness and contrast for each person. The images were processed with the artificial vision algorithm and then the FP were manually counted for comparison.

2.2. Fungiform papillae quantification by shape using normalized cross-correlation

A blue dye was applied to one half of the tongue. Then several images were taken. Next a 1 cm^2 grid was drawn using Photoshop (Fig. 1). The staining and the grid are used to aid the manual counting. This is not required by the algorithm that we propose.

Only the regions in the 3rd and 4th quadrants were processed, since they are representative of the total amount of fungiform papillae present on the tongue [14] (Fig. 1).

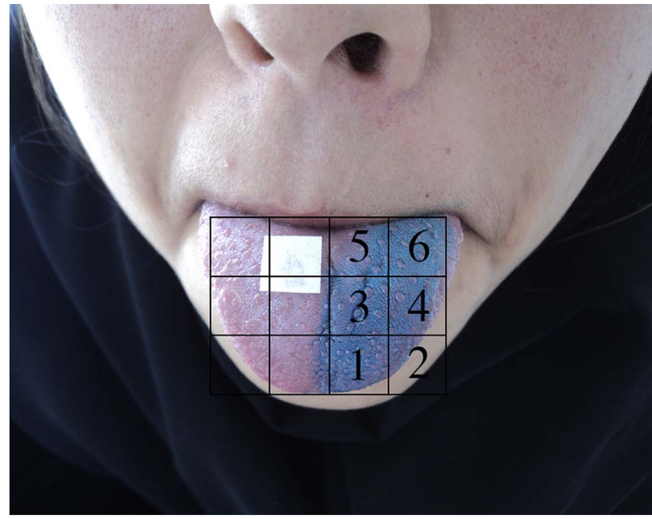

Fig. 1. Tongue stained with blue dye. A 1 cm^2 square grid is overlain showing the quadrants into which the tongue is divided.

Fig. 2. Average size fungiform papilla to be used as reference for matching.

2.3. Algorithm description

Objective: from a digital image of a region of a human tongue identify the positions of fungiform papillae and count them.

Input: a digital image showing a region of a tongue.

Output: identification and counting of fungiform papilla.

Steps of the algorithm:

1. Read the image to be analyzed.
2. Using the mouse, manually select two points to define a rectangular region which contains a characteristic fungiform papilla. This should be an average size papilla, not the smallest or the largest (Fig. 2). If the template is based on an FP that is too small, then the normalized cross-correlation is going to have a high value on a bigger region where a big FP is present, making it more difficult to detect the center position of a single FP, potentially maybe locating several peaks. If the template FP is too big, it is going to give a smaller value in the normalized cross-correlation in a smaller FP. We recommend choosing a template FP which is of average size. The example template is chosen for each subject and each photo.
3. Select the region of the image that will be searched for papillae. This is selected manually, providing two points to define a rectangular region that contains almost the whole image except for a small region where the matching window will not fit (Fig. 3).
4. Compute the cross-correlation matrix between the fungiform papillae template and the search sub-image. Since this works with a greyscale image, from the color image we are only using one of the channels, in this case the red channel. A different channel from the color image could be used, or either a greyscale image could be formed using all the channels. In this case, since the analysis is more oriented to shape than to color, the