Food Quality and Preference 40 (2015) 279–286

Contents lists available at ScienceDirect

Food Quality and Preference

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

Model of vegetable freshness perception using luminance cues

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ARTICLE INFO

Article history:
Received 13 September 2013
Received in revised form 16 May 2014
Accepted 14 June 2014
Available online 21 June 2014

Keywords:
Visual freshness perception
Luminance distribution
Image analysis
Statistics
Vegetables

ABSTRACT

Freshness perception is a quality discrimination process that influences our consumer choice and eating behavior, especially of highly perishable products such as vegetables. Previous research used photographic stimuli to investigate the relationship between luminance distribution and freshness perception for a cabbage leaf (C. Arce-Lopera, Masuda, Kimura, et al., 2013) and a strawberry (Carlos Arce-Lopera, Masuda, Kimura, Wada, & Okajima, 2012). In this study, the luminance and chromatic information of the freshness degradation process of four different vegetables (cabbage, strawberry, carrot and spinach) was recorded in a temperature, humidity and light controlled environment. However, instead of a camera, a 2D luminance and chromaticity analyzer (TOPCON UA1000) was chosen as the measurement equipment. Then, using a color management system to guarantee the exact reproduction of the recorded luminance and chromatic data of the real objects, a color and a grayscale version of the stimuli was created. Subsequently, those pictures were randomly presented to subjects who had to rate their perceived freshness using a visual analog scale. The achromatic results did not differ from the chromatic ones suggesting that luminance information is sufficient to enable an accurate estimation of vegetable freshness. Additionally, the original images were digitally manipulated only by modifying their luminance distribution and keeping their color information intact. When the resulting images were presented, using the same psychophysical experimental setting, the results showed that the perceived freshness also changed concordantly with the changes on the asymmetry of the luminance distribution. Finally, a model for vegetable freshness perception that utilizes only luminance cues is presented.

Introduction

Freshness perception is crucial when purchasing highly perishable products, such as fruits and vegetables (Correia & Rola-Rubzen, 2012; Wandel & Bugge, 1997). However, consumers describe the process of freshness discrimination as an intricate assessment that relates to a level of closeness to an ideal product in terms of distance, time and processing (Péneau, Linke, Escher, & Nuessli, 2009). This definition implies that consumers rely on sensory and non-sensory information about the product in order to achieve consent in their freshness assessment. The display of non-sensory information such as expiration date, time and place of harvest or even information on packaging and processing technology modify the consumer's perception of freshness and purchase intention (Ares, 2011; Deliza, Rosenthal, & Silva, 2003). On the other hand, sensory attributes related to consumer perception of freshness are beginning to be understood. In particular, visual features of the vegetable texture can include useful information for vegetable freshness perception. For instance, visual parameters such as shininess and bruise detection were reported as the best predictors for consumer freshness perception of strawberries and carrots (Péneau, Brockhoff, Escher, & Nuessli, 2007). For a more detailed review of consumer perception of vegetable freshness refer to Péneau et al. (2009).

Moreover, automatic visual analysis of food is increasingly gaining importance for assessing food quality (Sun, 2011). In particular, specific computer vision techniques were developed to investigate which visual features of several fruits and vegetables relate to their quality evaluation. For example, recent developments concerning automatic quality classification machines using image analysis of global shape and color information for strawberries (Liming & Yanchao, 2010), tomatoes (Arias, Lee, Logendra, &

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http://dx.doi.org/10.1016/j.foodqual.2014.06.010
0950-3293/

Janes, 2000), peaches and nectarines (Luchsinger & Walsh, 1993; Mitchell, 1987) were described. Even specific methods for quantifying non homogenous colors in food products were developed (Balaban, 2008) and compared with human classification performance (Balaban, Aparicio, Zotarelli, & Sims, 2008). However, those systems do not consider the relation between those visual features and the actual consumer perception of freshness, instead they use the real time of harvest which is independent from how consumers perceive the product.

Traditionally, classification algorithms for fruits and vegetables solely use color and deformation analysis when grading for quality (Sun, 2011). However, in the vision science field, luminance information is another visual cue that has been related with complex cognitive decisions about material perception such as glossiness perception (Motoyoshi, Nishida, Sharan, & Adelson, 2007), brightness perception (Fleming, Dror, & Adelson, 2003; Olkkonen & Brainard, 2010) and roughness perception (Ho, Landy, & Maloney, 2006). Even the human skin aging process is highly correlated with changes in the statistical information of the luminance channel (Arce-Lopera, Igarashi, Nakao, & Okajima, 2013). Using this insight, our research team was the first to experimentally prove that luminance information is enough for an accurate estimation of freshness perception of cabbages and strawberries (Arce-Lopera, Masuda, Kimura, Wada, & Okajima, 2013; Arce-Lopera et al., 2012; Wada et al., 2010). Moreover, even for individual differences in the stimuli, changes in luminance distribution correlated with degradation time and visual freshness perception of fish eyes (Murakoshi, Masuda, Utsumi, Tsubota, & Wada, 2013). All these results support the hypothesis of the crucial role of luminance distribution on the perceived freshness perception of food.

In previous research, experiments were conducted on the freshness perception of two vegetable textures by using photographs of the real stimuli. However, the luminance and chromaticity values of the displayed photographs are not equivalent to the exact same luminance and chromaticity values of the real objects. In fact, the photographs are the results of the light sensitivity of the camera sensors and of the resulting internal codification with respect to the camera settings. Therefore, the luminance and chromaticity values of the photographs are hardware-dependent, i.e. the luminance and chromaticity values depend on the camera used. To surpass this limitation, a special apparatus for taking the original images was used. Moreover, the freshness perception of two more vegetable textures, namely a carrot and a spinach leaf were evaluated. Finally, to independently test the effect of luminance statistics on the freshness perception, artificial stimuli were created for the cabbage stimuli by modifying one statistical parameter at the time.

Experiment 1

Apparatus

For the cabbage, spinach and carrot, the stimuli were presented in a 24.1-inch LCD monitor (ColorEdge CG245W, EIZO Co. Ltd.). For the strawberry, the recorded chromaticity values were outside the gamut of any conventional display. Therefore, to reproduce the exact chromaticity, a 6-primary projector setting (Yamaguchi, Haneishi, & Ohyama, 2008) had to be employed. The monitor and projectors luminance and chromatic calibration values were obtained using a photometric apparatus (SR-3A, Topcon Co. Ltd.). The distance between the display device and the observer was about 90 cm. A chinrest was used to fix the observer's head. The size of the stimuli was about 5.6×5.6 degrees of visual angle.

Stimuli

The vegetable stimuli were randomly selected from a local market. For all vegetables, the day of purchase was the initial day of the measuring session. No particular preparation was done to any vegetable. Each vegetable was simply unpacked and carefully separated without any cleaning done. All vegetables were already clean and ready to eat in their raw forms. For the strawberry, the luminance and chromaticity measurement session was done between the 18th and the 25th February 2011, the peak of the strawberry picking season in Japan. The information from the cabbage and the carrot was obtained from the 25th to the 29th March 2011. A leaf of the cabbage and a whole carrot were used. For the spinach, the information of one leaf was measured from the 10th to the 14th November 2011. In a measurement session, the stimuli were placed on top of a box covered by a matte material that served as background. Then, its luminance and chromaticity information was measured each 30 min for several days. For the measurement, a 2D luminance and chromaticity analyzer (TOPCON UA1000) was used. All the equipment was inside a controlled environment where the temperature and humidity were kept at 30 °C and 6%, respectively. These values were chosen to simulate a rapid deterioration of the vegetables within the limits of the measurement equipment operational capabilities. Therefore, for each vegetable at least 192 measures (2 measures each hour for 24 h for 4 days) were obtained. Then, for the experiments, five samples for each vegetable were selected, including a high and a low freshness reference. The high freshness reference was chosen to be the first measurement, i.e. at 0 h, to support the hypothesis that freshness temporarily degrades. The next step was to choose the low freshness reference. For each vegetable, the low freshness reference was chosen to be the time where the vegetable did not seem appetizing anymore. This assessment process was done arbitrarily by the authors. For the cabbage, the low freshness reference was set to 8 h after the start of the measuring session. For the strawberry, the carrot and the spinach, it was set to 72, 18 and 66 h, respectively. The remaining 3 stimuli were selected as indicated in Figs. 1–4. Then, using a color management system to guarantee the exact reproduction of the recorded luminance and chromatic data, a color and a grayscale version of the stimuli were created. Finally, the images were cropped to square patches to eliminate global cues such as size and shape of the object. The visual stimuli for the cabbage, the strawberry, the carrot and the spinach can be viewed in Figs. 1–4, respectively. However, the reader must remember that these visual representations were built to be displayed in special calibrated monitors and projectors. Therefore, the images shown need to be considered only as examples for the general viewing conditions but do not represent the exact luminance or chromaticity values of the real objects.

Procedure

After a dark adaptation period of 10 min, subjects binocularly observed the stimuli presented on the CRT screen. Using a counterbalance experimental design, two separate sessions that were different only on the stimuli type presented (color or grayscale) were conducted. Stimuli were presented in random order. Subjects were asked to rate their perceived freshness of the stimuli using a visual analog scale (VAS) represented by a slider in the computer screen and controlled by a computer mouse. There were 120 trials (5 images $\times$ 3 repetitions $\times$ 2 stimuli types $\times$ 4 different vegetable textures) for each subject. At the beginning of the experiment, two reference images were presented; a high and a low freshness reference. The references were set to 150 and 50 out of 200 in the visual analog scale, respectively. Both freshness references were the full picture of the vegetable texture before the cropping