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Comparison of jaw tracking by single video camera with 3D electromagnetic system

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ABSTRACT

The breakdown of food during chewing is both a physical process and a sensory experience. In trying to understand the differing sensory responses of consumers to food products it is useful to be able to measure their physical chewing action. In this paper we report the results of a comparison between a simple 2D video jaw tracking method with a 3D method using the JT-3D™ Jaw Tracker (BioRESEARCH Assoc., Inc., Milwaukee), on four model gel systems. The video and JT3D systems gave similar values for number of chews, chewing time, chewing cycle time, chewing frequency, opening velocity, and proportion of crossed/crescent/circle shaped cycles. Although timing of the three phases of a chew and vertical and lateral movement were different between the two methods, the effect of the different model gels on these parameters are similar in direction by the two methods for vertical and lateral movement, and opening and closing velocity and closing time. Our study demonstrates that for sensory evaluation of foods and consumer preference, where large numbers of participants are required to cover the variation in human populations, the simple 2D video method allows jaw movement to be tracked with sufficient accuracy to detect the effects produced by different foods.

1. Introduction

Food texture influences consumer preference. Designing textural properties of foods that consumers prefer requires an understanding of the relationship between food texture, oral processing and food structure. Model or homogenous foods, such as caramel confections and whey protein gels, have been used to examine these relationships (Brown and Braxton, 2000; Çakir et al., 2012a; Çakır et al., 2012b; Foster et al., 2011; Peyron et al., 1996; Woda et al., 2006). Textural properties have been shown to correlate with jaw movement and food structure (Çakır et al., 2012b; Foster et al., 2006; Koç et al., 2014; Peyron et al., 1996). Food structure and rheological behavior have been related to alteration of chewing strategy (Çakır et al., 2012b). Chewing duration was found to correlate with sensory cohesiveness, particle size distribution and breakdown rate (Çakir et al., 2012a; Foster et al., 2006). Food structure, particulate verse coarse stranded whey protein and carrageenan gels, were differentiated using oral processing (Çakir et al., 2012a).

Methods used for measuring jaw movement during chewing can be divided into two groups. The first group comprises methods based on tracking a marker or transducer that is physically attached to the teeth. A small magnet attached to the lower incisors is tracked via a rig that sits on the subject's head, e.g. JT-3D Jaw Tracker (BioRESEARCH Assoc., Inc., Milwaukee). Articulography uses multiple transducers attached to the teeth with wires to a control box outside of the mouth to track jaw movement (Carstens Medizinelektronik GmbHNelkenweg 8, D-37120 Bovenden). An alternative method uses accelerometers attached to the teeth. The second group uses skin surface markers or features to track the movement of the chin or other facial features inferring the movement of the jaw. Methods using a single camera and mirror (Kinuta et al., 2005; Pinheiro et al., 2011) and multiple cameras (Furtado et al., 2013; Röhrle et al., 2009) allow 3D reconstruction of jaw movement. More recently the use of a depth camera (Microsoft Kinect V1, Microsoft Corp., Bellevue, Washington, USA) (Tanaka et al., 2016) has been used for markerless jaw tracking in 3D.

Methods that attach a foreign object to the teeth or have wires that interfere with occlusion are invasive. This is likely to interfere with the sensory experience of the food. Häggman-Henrikson et al. (1998) observed markers attached to teeth significantly influenced

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natural chewing behavior. Using skin markers alone sacrifices accuracy for less intrusiveness and speedier setup. Using multiple camera systems to produce 3D coordinates, Häggman-Henrikson et al. (1998) found significant differences in displacement between the skin and teeth markers but that temporal measurements agreed within the precision of the system. Gerstner et al. (2005) found skin markers explained at least 74% of the jaw movement. Using skin markers is simpler and less invasive but multiple cameras require significant setup time and calibration to produce accurate 3D results.

Up to this point, the limitations of these jaw tracking methods have restricted the number of studies correlating consumer preference and jaw movement behaviors. The need to use a large number of participants for consumer preference studies would mean jaw tracking equipment needs to be minimal, simple and quick to apply. The equipment should be portable, but accurate enough to distinguish between the subjects' chewing responses to different foods. By using a headgear with four markers defining a plane that includes the chin marker, a homographic transformation of a single camera image can be made allowing compensation for head movement. This allows the accurate measurement of 2D chin movement. Using this system, a larger number of participants could be measured giving a large data set appropriate for sensory and consumer study correlations.

The aim of the present study is to evaluate the accuracy of a single camera 2D video system against a magnetic tracking system, the JT-3D Jaw Tracker (BioRESEARCH Assoc., Inc., Milwaukee), which accurately tracks the lower incisor in three dimensions. The present study looks at the absolute accuracy of the two systems, as well as their ability to measure changes in chewing parameters using four model gels of different chewing durations as influenced by varying food structure.

2. Materials and methods

2.1. Gel preparation

Four types of solid model gels were prepared. Three gels were made using 12% (w/w) protein from whey protein isolate (WPI). Treatments were 1) pH 7.0, 25 mM sodium chloride and 10 mM calcium chloride; 2) pH 7.0, 25 mM sodium chloride; and 3) pH 6.0, 25 mM sodium chloride. The fourth gel treatment was made using 3% (w/w) gelatin (Knox brand, Kraft Foods, Northfield, IL, USA). These treatments were selected because of differences in microstructure. Adding calcium chloride or lowering the pH to 6.0 creates a gel with a general particulate nature, while sodium chloride alone creates a gel with stranded structure (Mulvihill and Kinsella, 1988; Urbonaite et al., 2016).

WPI and salts were hydrated with deionized water that made up 80% of the water needed for the total solution weight; the solution was mixed with a magnetic stirrer for 3 h. After pH adjustment using 1 N HCl, the solutions were brought to final weight and allowed to rest overnight at 4 °C. Solutions were then poured into glass tubes of 19 mm inner diameter and heated at 80 °C for 30 min for WPI gels. Gelatin solutions were made by heating deionized water to a boil and adding gelatin while stirring. Gelatin solutions were poured into glass tubes of 19 mm inner diameter and allowed to cool to room temperature. All gels were stored until used in glass tubes at 4 °C. Gels at 4 °C were presented to subjects for oral processing.

2.2. Subject selection

Ten subjects between the ages of 22 and 35 years of age were selected for the study (9 female and 1 male). The study was conducted in accordance with the North Carolina State University Institutional Review Board for the Protection of Human Subjects in Research guidelines (IRB #3327). Subjects had Class I type molar occlusion and no missing teeth with the exclusion of third molars or wisdom teeth. The specific dental requirements can be found in Çakir et al. (2012a). Subjects did not have previous descriptive sensory training and participated voluntarily with written consent. Prior to the study beginning, subjects attended a preliminary session to ensure comfort with the procedures, samples and environment. Screening of maximum jaw movement in three directions (vertical, anterior-posterior and lateral movement) was done to ensure unrestricted movement. Each session was started by observing the subject chewing gum to ensure the equipment was functioning properly. A standardised experimental procedure was followed.

2.3. Experimental procedure

Jaw movement, recorded via two methods, and muscle activity were recorded simultaneously. Muscle activity results were not used in this analysis. Mandibular movement was recorded via a Jaw Tracker (JT-3D, Bioresearch Inc., Milwaukee, WI) which records incisor-point movement (Çakir et al., 2012a). A magnet is adhered to the center of the lower front incisors using stomahesive (ConvaTec, Bristol-Myers Squibb Company, NJ). Movement was followed in the vertical, anterior-posterior and lateral directions during mastication by an array of magnetic sensors in a unit that sat on the head (Fig. 1). Data was captured at 5000 (times/s).

Simultaneously measurement of video jaw movement was made using a dot sticker and markers attached to the Jaw Tracker head unit. A black dot surrounded by a white ring sticker was adhered to the skin in the centre of the subject's chin. Four dots were attached to the head unit positioned so that they formed the corners of a 2D plane that included the chin of the subject. The dots provided a reference plane in which to track the dot on the chin during image analysis (Fig. 1). Video was recorded using a Fujifilm XF1 compact digital camera (Fujifilm Corporation, Tokyo, Japan) at 30 frames/second in HD resolution (1280 × 720 pixels).

2.4. Data collection

Samples were presented to subjects in one session approximately 45 min in length. Each treatment was presented twice (4 × 2) randomly within one session. Subjects were seated upright

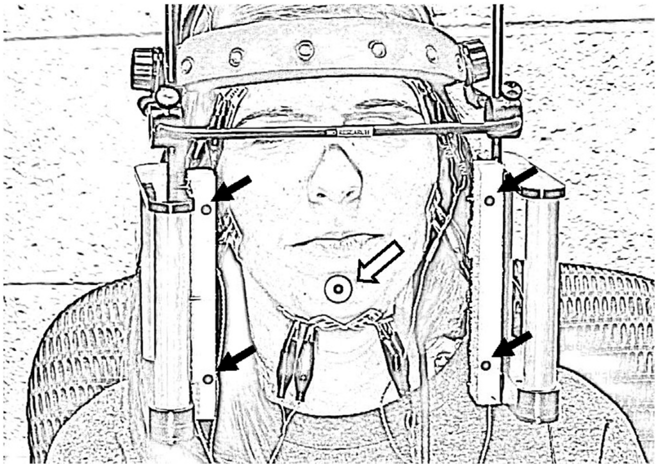

Fig. 1. Jaw Tracker head unit showing locations of the four video tracking dots used to generate a 2D plane (solid arrows), and chin dot (hollow arrow).