Measuring eating capability, liking and difficulty perception of older adults: A textural consideration.

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Abstract

Malnutrition in older adults is partly attributable to decreasing muscle strength leading to inadequate intakes. It is therefore important to investigate ways of identifying eating capability both through objective measures of strength and subjective measures of perceived difficulty and liking. In addition, food texture design might affect the oral processing and the difficulty perceived. Therefore the present study sets out to examine the relationship between various quantitative measures of eating capability (EC) and perceived difficulty of processing foods and gels varying in hardness in older adults. Tests were conducted on 30 participants (mean age 79 $\pm$ 9.4 years) using non-invasive techniques (hand gripping force, tongue pressure, biting force, and hand dexterity) in conjunction with frame-by-frame video recording analysis of chewing and swallowing of food stimuli and ratings of eating difficulty. The EC scores were computed to grade the population into three different groups. Stimuli were classified into two categories: food products and flavourless hydrocolloid gels with different inhomogeneity (textures). The EC parameters did not correspond to oral residence time, or the difficulty perceived. Bite force differed by EC group, and was significantly different by dental status [$F(3,4.26)=3.842$, $p=0.022$], and influenced both liking and number of chews. The food hardness (r=0.915, p=0.01) was significantly correlated with the number of chews. Gel heterogeneity influenced food oral processing behaviour. Oral residence time was significantly correlated with number of chews, liking and difficulty perceived. In summary, dental status and bite force of older adults are determining EC parameters to design optimized food-texture.

Keywords: older adults; eating capability; dental status; gel heterogeneity; oral residence time

1 Introduction

A global shift in demographics predicts that with greater medical care, social advancement and survival rates, the number of people over the age of 60 is expected to double by the year 2050 (WHO, 2015a). According to the WHO this will require changes in how older adults are viewed and treated, especially to ensure that older adults have improved health in their final years. In particular, the WHO promotes the idea that living longer is not enough, but that nations should ensure that "these extra years are healthy, meaningful and dignified" (Dr Margaret Chan, Director-General of WHO, 2015).

Therefore, although ageing is characterised by a decline in physical capacity (Balagopal, Rooyackers, Adey, Ades, & Nair, 1997; Fleg & Lakatta, 1988; Kenny, Yardley, Martineau, & Jay, 2008; Mingioni et al., 2016; Vita, Terry, Hubert, & Fries, 1998) and poorer mental health (Lange-Maia et al., 2016); there is nevertheless opportunity to identify changes associated with ageing to intervene early to promote health. One example of this is to characterise problems such as loss of appetite and develop solutions to improve nutritional status in older adults (Nieuwenhuizen, Weenen, Rigby, & Hetherington, 2010). Another example is to quantify eating capabilities so that interventions can be developed to support older adults to eat well despite changes in masticatory function. Thus, with ageing, mastication time and the time taken to swallow are greater due to a decrease in masticatory function (Matsuo & Palmer, 2009) which in turn affects food choice and dietary intakes (Hildebrandt, Dominguez, Schork, & Loesche, 1997; Ranta, Tuominen, Paunio, & Seppänen, 1988; Walls & Steele, 2004).

Ageing increases difficulties in the physical characteristics of the eating process. Older adults report anorexia and fail to consume adequate energy and nutrients. Ageing involves tooth loss, and changes in muscle function both of which compromise masticatory efficiency (Fontijn-Tekamp et al., 2000; Miyaura, Morita, Matsuka, Yamashita, & Watanabe, 2000). The contacting area between upper and lower teeth is highly important for food breakdown, also fewer teeth is associated with a decrease in biting force (Laguna, Sarkar, Artigas, & Chen, 2015). Replacing missing teeth with dentures can improve mastication but cannot always fully recover the efficiency of natural teeth (N'Gom & Woda, 2002). People who have lost post canine teeth and replaced with removable dentures (Fontijn-Tekamp et al., 2000; Kapur & Soman, 2006; Pocztaruk, Frasca, Rivaldo, Fernandes, & Gavião, 2008) have a much reduced masticatory function. For these reasons older adults who usually suffer from more tooth loss often have partially depleted mastication capability.

The mastication process is generally assessed by measuring particle size after chewing specific edible food stimuli such as peanuts, almonds, cocoa, carrots, jelly, hazelnuts, decaffeinated coffee beans, chewing gums or gelatin gels (Ahmad, 2006; Gambareli, Serra, Pereira, & Gavião, 2007; Schneider & Senger, 2002) or non-edible stimuli such as silicone-based artificial materials Optosil®, Optocal Plus® and CutterSil® (Fontijn-Tekamp, Van Der Bilt, Abbink, & Bosman, 2004) and leak-proof polyvinyl acetate capsules (de Abreu et al., 2014). In all of these cases, the stimulus is expectorated before swallowing and is then studied for particle size distribution.

However, these methods share the same disadvantage, namely that both saliva and particles can be swallowed accidentally during chewing which will cause inevitable experimental error. Studies which can assess mastication in other ecologically valid ways can reduce error and improve understanding of changes with ageing.

Regarding the swallowing process, clinical studies rely upon techniques, such as videofluorography and fiberoptic endoscopy exist (Hori et al., 2009; Langmore, 2003; Palmer, Drennan, & Baba, 2000; Yamashita, Sugita, & Matsuo, 2013). Although both techniques are very useful for studying swallowing, their use requires clinical training and both are invasive techniques, making them less accessible for research scientists and for community applications.

A recent study conducted within the EU-funded OPTIFEL project combined a series of strength measures in 203 elderly participants providing an overall "eating capability score" Laguna et al. (2015a), concept proposed previously by the same authors (Laguna & Chen, 2016). Measures included hand grip force, finger grip force, biting force, lip sealing pressure, tongue pressure and touch sensitivity. The collated and aggregated measure of "Eating Capability" or EC was then used to characterise four categories of participants from weakest to strongest and two intermediate groups. The aim of development of this eating capability tool was to group people by capabilities rather than age and to ultimately provide appropriately textured food to each group. The key limitation of currently developed eating capability model is that it is a relative scoring technique. Considering it is developed very recently, till now there are no reference values of all the eating capability components at all ages in the elderly population of different countries and hence strongest participant in each study is taken as the reference point. In the previous study (Laguna et al., 2015a), eating capability in UK participants and the Spanish participants were studied separately considering different strongest participant in each country and then the relative scores were compared. To test the functional utility of this classification, participants of different eating capabilities then rated food pictures on how difficult it was to manage that particular food by hand (manual cutlery manipulation such as cutting or picking up food) and by mouth (such as oral processing – chewing, biting, swallowing).

This research demonstrated strong correspondence between different measures of manual strength and indicators of oral/masticatory function. The proposal from this study is that grip strength could be a useful non-invasive proxy for masticatory function. Moreover the aggregated EC category was also meaningful in relation to perceived eating difficulty of various foods. Thus, participants from the weakest EC groups perceived fibrous and hard food products significantly more difficult to eat than participants with the highest EC score.

The present study was designed to extend these findings to include responses to real food stimuli and not only food photographs. The overall aim was to examine the relationship between measured eating capability and food oral processing variables such as chewing cycles, bolus-swallowing time as well as subjective variables such as perceived difficulty and liking of the food stimuli.

To enhance the measurement of real difficulties during eating, (mastication and swallowing) participants were filmed during the study to capture actual oral processing time for each food stimulus varying in hardness. This is a non-invasive method which has ecological validity and is relatively simple to undertake. A pilot study was done in young population to check its validity and to identify any difficulty in the performance (Laguna et al. 2016). Since dental status is likely to influence oral processing time and eating capability, the relationship between dentition, EC, oral processing and subjective measures was also investigated.

In summary, using a variety of measurements to characterise eating capability (directly and indirectly) it was predicted that difficulty in oral processing (actual and perceived) would increase with age and that it would differ according to eating capability score and dental status in a diverse group of older adults in response to food stimuli of varying hardness and matrix heterogeneity.

2 Methods

2.1 Participants

Recruitment of participants

United Kingdom. A total of 9 participants (over 65 years old, 6 women and 3 men) were recruited from a local community centre (Morley) and one private accommodation through the Neighbourhood Network Scheme in the area of Leeds (Yorkshire, UK).

Spain. A total of 21 participants (over 65 years old, 6 women and 15 men) were recruited in the area of Baix Emporda (Girona, Spain) from one nursing home and one community centre.

To be included in the study, participants had to be aged over 65 years with no acute pain in the upper extremities and oral areas. Participation in the study was voluntary. For the entire experimental procedure, participants were tested in their place of residence by the researcher who visited them either in the community centres, private homes or nursing homes. All the experimental procedures followed ethical guidance set by the University of Leeds, UK. Ethical approval was obtained from the Faculty Ethics Committee at the University of Leeds (MEEC 14-018, amendment July 2015) for UK and from the Comitè Ètic d'Investigació Clínica Institut d'Assistència Sanitària, Girona for Spain.

2.2 Eating capability score

Eating capability (EC) can be defined as the *physical, physiological, and cognitive capabilities of an individual in handling and consuming food.* For the present study the EC involved a composite score (see below) for grip strength (left and right hand), manual dexterity and oro-facial muscular capability (bite force and tongue pressure). All measurements were done in duplicate. The previous version of the eating capability measurement (Laguna et al., 2015 a, b) included finger grip force and toch sensitivity. However, due to the high coordination and precise movement required to execute finger force measurement, participants found it difficult to do the test. Furthermore, finger grip was not related with the overall capability of eating as demonstrated by Laguna et al. (2015, a, b). Also, touch sensitivity score was removed, because it’s implication on overall eating action was rather limited. A tool that was more relevant in terms of gripping and moving objects during the eating process was needed; hence, the manual dexterity measure by a standardized kit (described below) was introduced and the score was used to measure the eating capability.

The eating capability (EC) score was calculated using the following equation :

$$EC = \frac{\left(\frac{RH_{Par}}{RH_{Str\ Par}}\right) + \left(\frac{LH_{Par}}{LH_{Str\ Par}}\right)}{2} + \left(\frac{BF_{Par}}{BF_{Str\ Par}}\right) + \left(\frac{TP_{Par}}{TP_{Str\ Par}}\right) + \frac{\left(\frac{RD}{RD_{Str\ Par}}\right) + \left(\frac{LD_{Par}}{LD_{Str\ Par}}\right)}{2}$$

where, *RH* is the right hand gripping force (kg), *LH* is the left hand gripping force (kg), *BF* is the biting force (kg), *TP* is the tongue pressure (KPa), *RD* is the right hand dexterity count and *LD* is the left hand dexterity count (using manual dexterity kit). Subscripts $_{Par}$ and $_{Str\ Par}$ represent the individual and strongest individual scoring the highest in that particular test, respectively.

The maximum EC score was 4-points having each test measurement contributing to a maximum of 1-point. To calculate the value of each force for every individual, a fraction was generated. The denominator was the maximum value obtained for the test by the strongest participant, and the numerator was populated with values for the participant under study. Participants with eating capability < 2 were placed in cluster number one (the weakest group); participants with eating capability >2 and < 3 were placed in cluster number 2, participants with eating capability >3 were placed in cluster 3.

2.2.1. Measurement of eating capability components

Measurement of muscle strength

Physical strength measurements for grip strength, tongue pressure and bite force were measured using the methodology described in more details previously (Laguna et al., 2015). In brief, hand griping force was measured with an adjustable handheld dynamometer (JAMAR dynamometer, Patterson Medical Ltd., Nottinghamshire, UK); bite force with a thin flexible force transducer (Tekscan, South Boston, Massachusetts, USA) with two adhesive silicon discs (diameter: 1.5 cm, thickness: 0.3 cm to sandwich the force sensor) connected to a multimeter; and tongue pressure was measured using the Iowa Oral Performance Instrument (IOPI®, Medical LLC, Redmond, Washington, USA). Before using the equipment, each measurement was demonstrated to the participant by a trained researcher and any questions were answered.

Coordination and dexterity

A standardized kit for manual dexterity was used. Individuals move, one at a time, the maximum number of blocks from one compartment of a box to another of equal size, within 60 seconds. This kit provides a baseline for motor coordination. The test is quick and simple to administer and it is suitable for persons with limited motor coordination (Mathiowetz, Volland, Kashman, & Weber, 1985).

Researchers followed the norms published by (Mathiowetz et al., 1985). The test box was placed lengthwise, and each subject was seated facing the box, the researcher was seated in front facing the participant. When the researcher indicated, the subject grasped one block at a time with the dominant hand transported the block over the partition and released it into the opposite compartment. This activity was carried out during a minute, after which the test was stopped, and then the test was resumed with the non-dominant hand. If the participant did not cross the partition at least with the tip of their fingers or carried more than one block, then, it was not counted.

In this study, data were classified by age, gender and dominant hand. In average, participants over 65 years old moved 27-28 blocks and over 75 years old moved 25-26 blocks.

Dental status

In the present study, participants were asked about their dental status and were separated into four different categories: natural teeth; bridge and crowns; dentures; and edentulous (no teeth or dentures at all). One participant had only upper dentures and another participant had implants, neither of them (2) was taken into account for the statistical analysis of dental status.

2.3 Observational study (video-recording): mastication and oral residence time

Prior to the video recording session, participants were given a complete explanation of the procedure: that they would be offered different food products to chew and swallow normally in the order that they prefer whilst they are video-recorded. They were shown two black trays: one with hydrocolloid gels of different textures and one with real food products. Participants were told that they could stop at any time and could withdraw from the study without prejudice. They were also informed that in case of any of the product causing discomfort, they did not have to eat it. They were aware that the main focus of this video-recording session was to record their mastication and swallowing behaviour. An example of chewing cycle and swallowing is shown in Figure 1.

Despite testing in different contexts, the researcher created an environment which was standard for comfort, quiet and minimal distractions. The researcher was seated in front of the participant, beside the camera. The researcher assisted participants with tissues or water if requested, but water was not offered at the beginning. Participants were given the food stimuli to eat in their customary manner whilst they were recorded via video camera (Canon Powershot SX500 IS). Videos were analysed to record the number of chew cycles and swallowing time. One chew cycle was considered as the mandible movement upward and downward, the final number of chews was the sum of chew cycles from when the participant placed the food inside the mouth up until the action of swallowing. To record the time at swallowing, researchers observed two factors: lip seal force increment and consequent down turning of the lip corners followed by paused breathing and pharynx movement. The swallowing process was considered finished once the participant had resumed breathing, normally shown by slight mouth opening (see figure 1B).

Frame-by-frame analysis of all videos was done in duplicate. In case of a difference in the number of chewing or time, that participant's video was re-studied a third time.

Subjective ratings of difficulty and liking

Participants used a Visual Analogue Scale (100 mm) anchored by words to score their difficulty (least difficult to most difficult). Participants were asked: *How difficult is for you to eat this food product?*

Also since perceived difficulty may be moderated by how much a food is liked, participants were asked: *How much do you like the food product?* The participants scored their liking for the food stimuli on a 9 point hedonic scale (1= dislike extremely to 9= like extremely). (L270-276)

2.4 Food stimuli

Preparation of model hydrocolloid gels

κ-Carrageenan and sodium alginate were both obtained from Special Ingredients (Sheffield, UK). Calcium chloride was obtained from Mineral Water (Purfleet, UK). All three ingredients were food grade and used without any further purification.

Calcium alginate beads production (CAl). Firstly, sodium alginate solutions were prepared by slowly adding the exact quantity of the powder in distilled water. The obtained dispersion was heated and stirred for 1 h at 90 °C to ensure complete solubilisation. Calcium chloride solutions (2M) were prepared by dissolving the required quantity in distilled water. For the preparation of big beads (median diameter 1300 μm), sodium alginate (Na alginate) solution was extruded using a 0.8 mm nozzle syringe (Terulo, Neolus) into the calcium chloride bath. For the small beads (median diameter 57 μm), sodium alginate solution was sprayed at 50-55 mL/min over a calcium chloride bath using jet sprayer (0.45 mm nozzle diameter). The bead size was measured using static light scattering (Malvern MasterSizer 3000, Malvern Instruments Ltd, Worcestershire, UK). The Na-alginate beads were cross-linked by Ca^{2+} ions to form sprayed Ca-alginate beads. Both beads remained in the $CaCl_2$ bath for 30 minutes; the prepared beads were removed and washed with deionized water twice to remove any non-cross-linked Ca^{2+} ions.

κ-Carrageenan gel production (1κ-2κ). 1-2 wt% of *κ*-carrageenan was prepared by dissolving appropriate quantities of κ-carrageenan in distilled water and mixing by magnetic stirring for a few hours at 80 °C to facilitate hydration.

κ-Carrageenan and sodium alginate gel production (M-κSAl). Binary gel preparation involved dry blending of appropriate quantities of *κ*-carrageenan and sodium alginate and dissolving in distilled water (2 wt%) followed by magnetic stirring for a 45 minutes at 80 °C.

κ-Carrageenan and calcium alginate bead production (B-κCAl/ S-κCAl). Small (spray) or big beads were added to a tray (12×7.5×1.5 cm), then, *κ*-carrageenan solution of 1 wt% concentration (80 °C) was poured in to the tray in 1:1 w/w. After storage at 4 °C for 24 h, gels were cut in a circular shape (2.0×1.0 cm; diameter x height).

Food products

Fifteen commonly consumed food products: pear, carrot, apple, banana, watermelon, pineapple, potato, gherkin, baby sweetcorn, heart of palm, mild cheddar, medium mature cheddar, mature cheddar, mozzarella and soft, spreadable cheese were initially analysed using penetration tests. This test simulates the puncture of an incisor tooth biting through food; data is recorded in a force-time curve. The probe used (Volodkevich Bite Jaw, wedge with a cross sectional dimensions 10mmx10mm) was attached to the Texture Analyser (Texture analyser, Stable Micro Systems, Godalming, UK) and samples were placed on a flat platform (test settings: 1 mm/s, for a distance= 10 mm, trigger force= 5 g).

Then, five foods were selected according to their different breakage profile or maximum break at force at break as a function of distance (data not shown) taking into account dentition status of the participants, these were: mild cheddar (soft), mature cheddar (hard), mozzarella cheese, banana, and canned diced potato.

Fracture behaviour of food stimuli

To characterize the mechanical properties of the food stimuli used in this study, fracture mechanics were tested by a penetration test (using the upper Volodkevich Bite Jaw). For gels, additionally a compression test using 75-mm diameter aluminium plate (P/75) (Texture analyser, Stable Micro Systems, Godalming, UK) was done. As it has been described in the previous section, samples were placed on a flat platform and the probe was brought down at a controlled speed of 1 mm per second for 10 mm and at a trigger force of 5 g. Each test was performed with five repetitions for each sample. The maximum force (N) was taken as a measure of hardness.

2.5 Statistical analysis

In order to test the hypothesis that objective measures of eating capability and oral processing would correspond to subjective eating difficulty and liking of food stimuli, a series of statistical tests were performed. Pearson's correlation was calculated to examine the relationships between independent indicators of muscle strength (grip force, bite force, tongue pressure). Correlations (Pearson's correlation) between time and number of chew, likeness score and difficult perceived per participant and stimuli were also studied. This analysis was performed using XLSTAT 2009.4.03 statistical software (Microsoft, Mountain View, CA).

Analysis of variance (one-way ANOVA) was applied to study the difference among participants according to grouping by dental status, and eating capabilities groups. A one-way multivariate analysis of variance was performed to study how different factors (number of chews, liking and difficulty) could influence in the oral processing time. The entire ANOVA tests were done using SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

3 RESULTS

3.1. Strength results

Descriptive data from the strength measured in the 30 participants are summarised in Table 1.

[TABLE 1 here]

Age was inversely related with grip strength and manual dexterity left hand (see Table 2). Grip strength was significantly associated between left and right hands, also with manual dexterity score and tongue pressure but not with bite force.

[TABLE 2 here]

3.2. Eating capability score

The Eating capability (EC) of the different groups is presented in Table 3. Participants were grouped into EC1 with a score from 0 to 2 (lowest eating capability) group; those with a score between 2 and 3 were intermediate EC2 and the participants of EC3 had the highest scores (from 3 to 4). Participants classed in EC3 were younger and stronger, they had significantly higher ($p<0.05$) hand grip and were quicker in the kit for manual dexterity, however this group of participants had only three participants. Therefore, the differences must be interpreted with caution.

[TABLE 3 here]

Tongue pressure had higher variability, therefore, averages were different between the EC1 and EC2-EC3, but were not statistically significant (p=0.105). Bite force was significantly different among eating capability groups (p<0.05), lowest bite force was executed by EC1 group, whilst EC3 were the strongest. Regarding the oral residence time, the variability inside the groups was too great to detect significant differences between the EC groups; and it was not a clear trend for gels and food.

On average, EC1 participants scored perceived difficulty lower than EC3 participants but this was not significant (p=0.470, p=0.705). This also can happen because the food given to the participants was previously chosen by researchers in order to be "easy" to avoid choking.

3.3. Influence of dental status

In this study, participants were grouped according to their dental status; data is presented in Table 4. Those participants with natural teeth were able to execute significantly higher biting force than those participants with denture or edentulous participants. [$F(3,4.26)=3.842$, $p=0.022$].

As it can be seen in Table 2 bite force did not correlate significantly with any other individual indicators of EC.

[TABLE 4 here]

Edentulous participants needed to chew significantly more (p<0.05) the *1κ* gel. Participants with natural teeth or crown, chew significantly less (p<0.05) heterogeneous samples (*B-κCAl) (see figure 2).* No difference was found among participants masticating the food products given, probably due to the soft and homogeneous structure of the food.

[FIGURE 2 here]

For a better understanding of the influence of biting force into the liking score of gels and food products, participants' bite force was segregated into three groups with weak (N=7), moderate (N=8) and strong bite force (N=10) (see Figure 3). Participants with the strong bite force rated liking for foods higher than those in the weak bite force but this failed to reach significance (p>0.05).

[FIGURE 3 here]

3.4. Influence of food fracture and homogeneity

As it can be observed in Figure 4a, the number of chews needed to swallow the gels did not correlate significantly with their instrumental hardness (r= 0.754, number of samples, gels, correlated=5). When the maximum force at break was similar, the time in mouth was dependent on the food heterogeneity (i.e. irregularities in the matrix), and the time in mouth increased with the heterogeneity increment (e.g. number of beads). However, at the same level of homogeneity, harder gels (2*κ*) needed more chews than the softer gel (1*κ*). Figure 4b shows the plot of the number of chews and the maximum force at break of the food products. In this case, a trend can be observed with the instrumental hardness because the three matrices were quite homogeneous. Although gels were generally harder than food products, the number of chews in gels (n=30.67±17.5) was similar to the number of chews of food products (n=29.33±11.5), (Figure 4b).

[FIGURE 4 here]

3.5. Oral residence time dependency

Figure 5 shows the influence on oral processing time of different factors: number of chews, liking and difficulty.

In this study, the participants were required to masticate freely. In Figure 5, the relation among time and number of chews, liking score and difficulty are shown (N=279). As can be observed in Figure 5a, there is a significant and high correlation between number of chews and duration in the mouth (gels=0.726, p=0.020; and food=0.658, p=0.018), therefore oral residence is related to chewing effort.

In Figure 5b a significant but a lower correlation between liking score and time kept in the mouth for gels (r=0.483, p<0.01) and for food products (r = 0.252, p<0.01) was observed. For the gels, liking score varied from 4 to 6.5, however foods were scored from 2.65 to 6.85. This suggests that since gels were unfamiliar, these were rated in the neutral to liked zone, whereas food products were familiar and participants were able to discriminate better between the items based on past experience.

In figure 5c, the relation between time in mouth and rated difficulty is shown. For food products there was a significant correlation with longer residence time related to perceived difficulty (r=0.252, p<0.01), for gels was this was also significant (r=0.291, p<0.01).

This meant that participants associated the difficulty with the oral residence time or time to swallow. Liking and difficulty were both associated with oral residence time for food products.

[FIGURE 5 here]

4. Discussion

The present investigation demonstrated that EC discriminates between older adults on the basis of age, manual dexterity and biting force. However, in the present study the EC failed to discriminate between participants on oral residence time, number of chews and perceived difficulty. Furthermore, grouping participants on the basis of their dental status (a close proxy for eating capability), was related to number of chews needed to process some of the food stimuli (gels), with their average liking and with the maximum bite force able to execute.

A previous study showed that hand force was correlated negatively with participant age (Laguna et al., 2015; Luna-Heredia, Martín-Peña, & Ruiz-Galiana, 2005) (Table 2). Ageing causes significant changes to hand morphology and function through commonly experienced skeletal diseases such as osteoarthritis, rheumatoid arthritis, and osteoporosis, as well as hormonal changes, and degenerative disease of the central nervous system such as Parkinson's disease (Carmeli, Patish, & Coleman, 2003). Also, in line with in our previous research (Laguna et al., 2015) hand force showed a low but significant correlation with tongue pressure. Participant's coordination and dexterity were also inversely correlated with age for both hands, and correlated significantly with the hand strength. It is worthwhile mentioning that from filming real time mastication, measures of the time at swallow and the number of chews can be made, but also facial gestures can be used to support subjective ratings of perceived difficulty. Also, food manipulated by hand was observed in the recorded videos, 8 of 30 participants lost the gels on the way from hand to the mouth several times, but these events did not correspond significantly to EC score.

Against our expectations the sum of components of the eating capability did not differentiate between the food oral processing parameters (oral residence time, number of chews and perceived difficulty). Each individual may have a different component of the eating capability depleted, and the sum of them does not discriminate enough to identify different patterns during the food oral processing in this small sample.

To our knowledge, till date, no normalized data for eating capability measurement is available, so authors have compared EC within the population studied. It is worth highlighting that EC groups cannot be compared between studies, as they are based on different parameters. However, EC components (hand force, tongue force) among different studies can be compared as they are based on the same objective measrements.

This study revealed a significant difference in the bite force between participants with natural teeth and those who wear dentures (see table 4), furthermore, those without teeth needed to chew more (figure 2).This means bite was less efficient; and effort (number of chew) was higher compared to those with natural teeth. These findings support previous studies where masticatory efficiency decreases with number of missing teeth (Fontijn-Tekamp et al., 2000; Miyaura et al., 2000); this is due to a decrement in the contact area between the upper and lower teeth, important for oral food breakdown. During the mastication, food is transformed continuously, this provokes a sensory feedback in the oral and pharyngeal cavities, adapting the chewing pattern (Palmer, Kuhlemeier, Tippett, & Lynch, 1993) up to the point that is considered safe to swallow. There is a normal interindividual variability in the number of chews, in middle age population (~43 years old) more bite force and better chewing performance is related with less number of chews (Avlund, Damsgaard, Sakari-Rantala, Laukkanen, & Schroll, 2002). The current study demonstrates this effect and shows the impact of ageing and tooth loss on masticatory function.

Although it was not statistically significant, liking was lower with less bite force (figure 3), this may be attributed to one or more factors. One is the loss of sensory experience of participants with less bite force (and less number of natural teeth). During a bite or chew, the pressure exertion on teeth causes slight stretching to the periodontal ligaments that send information to the central nervous system for interpretation of the textural properties of the food (Chen, 2009). The second factor that may influence liking is the effort required when one has less teeth. In the study of Hyland, Ellis, Thomason, El-Feky, and Moynihan (2009) patients involved explained how with the time, they have the feeling that loss of gum tissue reduced enjoyment of eating. Furthermore, when the denture is not well adjusted, the tongue is used to stabilize and aid retention of dentures, then, this not only will decrease the masticatory efficiency, the function of the tongue in positioning the bolus of food is less efficient (Bohnenkamp & Garcia, 2007).

In accordance with previous authors (Lassauzay, Peyron, Albuisson, Dransfield, & Woda, 2000), harder food products were kept longer in mouth. For the gels created, at the same level of hardness, when textural heterogeneity was present (B-*κ*CAl, S-*κ*CAl) participants kept them longer in mouth than gel samples with one texture (M-*κ*SA, 1*κ*). This might be attributed to the degree of structure due to the gel heterogeneity, which can play an important role in the fracture of the gels affecting the oral processing behaviour and oral residence time (Hutchings & Lillford, 1988). When comparing the three factors: number of chews, liking and difficulty number, liking and difficulty contribute similarly to the oral processing time (Figure 5). Several studies demonstrate the relationship between liking and sensory temporality (Delarue & Loescher, 2004; Thomas Carr & Lesniauskas, 2016), however few examine liking and overall time in the mouth. It could be that liked food will be kept longer in the mouth than food that is not liked since this may not be eaten, will be spit out or will be swallowed as soon as possible. In the case of the gels, three participants refused to eat them, and two asked to spit them out after being chewed. Overall liking was related with the texture perception for gels and for foods. Therefore, participants associated perceived difficulty with the oral residence time or time to swallow. This supports research by Çakır et al. (2012) and Takahashi Takahashi, Uzawa, Myo, Okada, and Amagasa (2009), who found a link between the duration of mastication and with the ease with which food is broken down to form into a cohesive bolus.

Four of the 30 participants indicated by facial expression (closing eyes or pointing the neck by hand) the difficulty experienced during eating. However they had a normal tongue pressure (average 43.5 kPa), and they belonged to different EC groups. Thus these facial expressions were not specifically linked to the ability to perform the right tongue pressure and swallow.

Limitations of the study

This study has several limitations. In order to keep the safety and comfort of the participants, food stimuli given were in the range of soft-solid food and this does not cover the whole range of food (hard solids such as carrots or nuts). Also, even though participants were instructed to avoid talking whilst eating, the majority made comments prior/post consumption, especially in the gels given as “are you sure that this is edible?”, “do I have to swallow?”, “it does not have any taste”, etc, This suggests that despite efforts to develop and characterise different gel matrices, older adults struggle with these unfamiliar systems when compared to real foods, which are familiar and acceptable. Finally, the sample size was small although measures of eating capability measurement were rigorously taken. Also it might be worth pointing out that gender had more influence on hand grip force and age had more influence on Tongue pressure measurements which might have influenced the overall EC score.

5. Conclusions

Overall, using a sample of 30 older adults, eating capability scores did not discriminate between objective and subjective oral processing measures However, dental status was significant in distinguishing bite, oral processing time, number of chews, and liking. This suggests that an important proxy for eating capability is dental status.

From a food design point of view, in this preliminary study, it has been elucidated that not only the consistency (hardness) of food structure but also the heterogeneity of the matrix affected food oral processing behaviour (number of chews and time in mouth).

The implications of this research are that to ensure good nutrition in older adults, eating capability can be determined in part by dental status and that this in turn affects oral processing, which can then influence food intake. Awareness of liking, perceived difficulty and objective parameters of eating capability can support decisions regarding which foods to offer older adults to optimise the energy and nutrient intakes to promote health and well-being.

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References

Ahmad, S. (2006). An insight into the masticatory performance of complete denture wearer. *Ann Dent, 13*, 24-33.

Avlund, K., Damsgaard, M. T., Sakari-Rantala, R., Laukkanen, P., & Schroll, M. (2002). Tiredness in daily activities among nondisabled old people as determinant of onset of disability. *Journal of Clinical Epidemiology, 55*(10), 965-973.

Balagopal, P., Rooyackers, O. E., Adey, D. B., Ades, P. A., & Nair, K. S. (1997). Effects of aging on in vivo synthesis of skeletal muscle myosin heavy-chain and sarcoplasmic protein in humans. *American Journal of Physiology-Endocrinology And Metabolism, 273*(4), E790-E800.

Bohnenkamp, D. M., & Garcia, L. T. (2007). Phonetics and tongue position to improve mandibular denture retention: a clinical report. *The journal of prosthetic dentistry, 98*(5), 344-347.

Çakır, E., Vinyard, C. J., Essick, G., Daubert, C. R., Drake, M., & Foegeding, E. A. (2012). Interrelations among physical characteristics, sensory perception and oral processing of protein-based soft-solid structures. *Food Hydrocolloids, 29*(1), 234-245.

Carmeli, E., Patish, H., & Coleman, R. (2003). The aging hand. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58*(2), M146-M152.

Chen, J. (2009). Food oral processing—A review. *Food Hydrocolloids, 23*(1), 1-25.

de Abreu, R. A. M., Pereira, M. D., Furtado, F., Prado, G. P. R., Mestriner Jr, W., & Ferreira, L. M. (2014). Masticatory efficiency and bite force in individuals with normal occlusion. *Archives of Oral Biology, 59*(10), 1065-1074.

Fleg, J. L., & Lakatta, E. G. (1988). Role of muscle loss in the age-associated reduction in VO2 max. *Journal of Applied Physiology, 65*(3), 1147-1151.

Fontijn-Tekamp, F., Slagter, A., Van Der Bilt, A., Hof, M. V. T., Witter, D., Kalk, W., et al. (2000). Biting and chewing in overdentures, full dentures, and natural dentitions. *Journal of Dental Research, 79*(7), 1519-1524.

Fontijn-Tekamp, F., Van Der Bilt, A., Abbink, J., & Bosman, F. (2004). Swallowing threshold and masticatory performance in dentate adults. *Physiology & Behavior, 83*(3), 431-436.

Gambareli, F. R., Serra, M. D., Pereira, L. J., & Gavião, m. b. d. (2007). Influence of measurement technique, test food, teeth and muscle force interactions in masticatory performance. *Journal of Texture Studies, 38*(1), 2-20.

Hildebrandt, G. H., Dominguez, B. L., Schork, M. A., & Loesche, W. J. (1997). Functional units, chewing, swallowing, and food avoidance among the elderly. *The journal of prosthetic dentistry, 77*(6), 588-595.

Hori, K., Ono, T., Tamine, K.-i., Kondo, J., Hamanaka, S., Maeda, Y., et al. (2009). Newly developed sensor sheet for measuring tongue pressure during swallowing. *Journal of Prosthodontic Research, 53*(1), 28-32.

Hutchings, J. B., & Lillford, P. J. (1988). The perception of food texture — the philosophy of the breakdown path. *Journal of Texture Studies, 19*(2), 103-115.

Hyland, R., Ellis, J., Thomason, M., El-Feky, A., & Moynihan, P. (2009). A qualitative study on patient perspectives of how conventional and implant-supported dentures affect eating. *Journal of Dentistry, 37*(9), 718-723.

Kapur, K. K., & Soman, S. D. (2006). Masticatory performance and efficiency in denture wearers. *The journal of prosthetic dentistry, 95*(6), 407-411.

Kenny, G. P., Yardley, J. E., Martineau, L., & Jay, O. (2008). Physical work capacity in older adults: Implications for the aging worker. *American Journal of Industrial Medicine, 51*(8), 610-625.

Laguna, L., & Chen, J. (2016). The eating capability: Constituents and assessments. *Food Quality and Preference, 48, Part B*, 345-358.

Laguna, L., Asensio Barrowclough, R., Chen, J., & Sakar, A. (2016). New approach to food difficulty perception: food structure, food oral processing and individual's physical strength. *Journal of Texture studies*, In Press, doi:10.1111/jtxs.12190

Laguna, L., Sarkar, A., Artigas, G., & Chen, J. (2015a). A quantitative assessment of the eating capability in the elderly individuals. *Physiology & Behavior, 147*, 274-281.

Laguna, L., Sarkar, A., & Chen, J. (2015b). Assessment of eating capability of elderly subjects in UK: a quantitative evaluation. *Proceedings of the Nutrition Society, 74*, E167-E167.

Lange-Maia, B. S., Newman, A. B., Cauley, J. A., Boudreau, R. M., Jakicic, J. M., Caserotti, P., et al. (2016). Sensorimotor Peripheral Nerve Function and the Longitudinal Relationship With Endurance Walking in the Health, Aging and Body Composition Study. *Archives of Physical Medicine and Rehabilitation, 97*(1), 45-52.

Langmore, S. E. (2003). Evaluation of oropharyngeal dysphagia: which diagnostic tool is superior? *Current opinion in otolaryngology & head and neck surgery, 11*(6), 485-489.

Luna-Heredia, E., Martín-Peña, G., & Ruiz-Galiana, J. (2005). Handgrip dynamometry in healthy adults. *Clinical Nutrition, 24*(2), 250-258.

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985). Adult norms for the Box and Block Test of manual dexterity. *American Journal of Occupational Therapy, 39*(6), 386-391.

Matsuo, K., & Palmer, J. B. (2009). Coordination of mastication, swallowing and breathing. *Japanese Dental Science Review, 45*(1), 31-40.

Mingioni, M., Mehinagic, E., Laguna, L., Sarkar, A., Pirttijärvi, T., Van Wymelbeke, V., et al. (2016). Fruit and vegetables liking among European elderly according to food preferences, attitudes towards food and dependency. *Food Quality and Preference, 50*, 27-37.

Miyaura, K., Morita, M., Matsuka, Y., Yamashita, A., & Watanabe, T. (2000). Rehabilitation of biting abilities in patients with different types of dental prostheses. *Journal of Oral Rehabilitation, 27*(12), 1073-1076.

N'Gom, P. I., & Woda, A. (2002). Influence of impaired mastication on nutrition. *The journal of prosthetic dentistry, 87*(6), 667-673.

Nieuwenhuizen, W. F., Weenen, H., Rigby, P., & Hetherington, M. M. (2010). Older adults and patients in need of nutritional support: review of current treatment options and factors influencing nutritional intake. *Clinical Nutrition, 29*(2), 160-169.

Palmer, J. B., Drennan, J. C., & Baba, M. (2000). Evaluation and treatment of swallowing impairments. *American family physician, 61*(8), 2453-2462.

Pocztaruk, R. d. L., Frasca, L. C. d. F., Rivaldo, E. G., Fernandes, E. d. L., & Gavião, M. B. D. (2008). Protocol for production of a chewable material for masticatory function tests (Optocal-Brazilian version). *Brazilian oral research, 22*(4), 305-310.

Ranta, K., Tuominen, R., Paunio, I., & Seppänen, R. (1988). Dental status and intake of food items among an adult Finnish population. *Gerodontics, 4*(1), 32-35.
Schneider, G., & Senger, B. (2002). Clinical relevance of a simple fragmentation model to evaluate human masticatory performance. *Journal of Oral Rehabilitation, 29*(8), 731-736.
Takahashi, K.-I., Uzawa, N., Myo, K., Okada, N., & Amagasa, T. (2009). Simultaneous Assessment of Cyclin D1 and Epidermal Growth Factor Receptor Gene Copy Number for Prognostic Factor in Oral Squamous Cell Carcinomas. *Oral Science International, 6*(1), 8-20.
Vita, A. J., Terry, R. B., Hubert, H. B., & Fries, J. F. (1998). Aging, health risks, and cumulative disability. *New England Journal of Medicine, 338*(15), 1035-1041.
Walls, A. W. G., & Steele, J. G. (2004). The relationship between oral health and nutrition in older people. *Mechanisms of Ageing and Development, 125*(12), 853-857.
WHO. (2015a). Ageing and health. *World Health Organization, Fact sheet N°404*.
WHO. (2015b). WHO: Number of people over 60 years set to double by 2050; major societal changes required. http://www.who.int/mediacentre/news/releases/2015/older-persons-day/en/.
Yamashita, S., Sugita, D., & Matsuo, K. (2013). Relationship between stage II transport and number of chewing strokes as mastication progresses. *Physiology & Behavior, 122*, 100-103.