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A comparison between young and elderly adults investigating the manual and oral capabilities during the eating process

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PRACTICAL APPLICATION

It is well understood that the elderly population is particularly vulnerable to malnutrition through decreased appetite which as a consequence affects health status. The level of proficiency in the associated food manipulation, mastication and deglutition executed during the process correlate with the eating proficiency or capability. To date, to the authors knowledge, there are no studies which address the eating capacity of the elderly population. It was observed that with increasing age, a corresponding decrease in deliverable force using the hand, finger and tongue was noted. Accompanying these findings, an increase in the threshold in texture discrimination (i.e. tactile and pair-wise comparison tests) was also found with the elderly female group exhibiting the greatest reduction in capacity. The findings in this work offer objective measures with which to develop novel foods specifically aimed at improving nutritional products for the elderly.

Abstract

The adequacy of food handling and eating performance is vital for human survival and well-being. However physiological weakness due to ageing can often lead to compromised living. This work investigated quantifiable parameters to find associations between age and the eating capability in young (n=36) and elderly sample populations (n=40). The primary focus was to evaluate the strength of hand (hand and finger grip), mouth (tongue pressure), and the capability of texture discrimination (touch sensitivity and gel firmness). It was observed that, with age increment, there was a decrease in all measured forces (hand, finger, tongue) and an increased threshold in the texture discrimination (tactile and pair comparison test); the most decreased capability was observed in elderly women. Further statistical analyses show that hand grip force was related to finger force, tongue pressure and texture discrimination. These results demonstrate that a clear physiological separation exists between the two age groups and that the eating capability of an elderly individual can be objectively evaluated.

Keywords: eating capability, age, hand grip force, texture discrimination

1. Introduction

It is generally recognised that the overall quality and sense of satisfaction of life are strongly influenced by one's nutritional status (Dean, 2009). However, with age, food and energy intake tend to decrease due to physiological and practical reasons. This reduced intake could compromise the nutritional status of elderly individuals, increasing the incidence of morbidities (Maitre *et al.*, 2014).

Furthermore, apart from some nutraceutical products, little effort has been made by the food sector in developing new products for the needs of the elderly consumers (Popper, 2003), leading to further restrictions on food variety and choice.

From a scientific perspective, research has been conducted to explain the decline of taste (Mojet *et al.*, 2005) and smell perception (Schiffman and Zervakis, 2002), or the ability to differentiate food texture (Fillion, 2003) in relation to the ageing process. The capabilities of perceiving sensory changes are very important for food enjoyment, and in the ability to conduct coordinated actions (in particular hand and oral actions) which are essential to perform an eating process. Woda *et al.* (2006) reviewed the mastication process in the old age, and noted that there is a reduction in bite force and muscle activity. Individuals who have edentulism (tooth-loss), have a reduced level of mastication efficiency (Fontijn-Tekamp et al., 2000; Miyaura et al., 2000). In summary, mastication capability in elderly populations is related to physical capability and dental status.

During the whole eating process, we observe and manipulate food with cutlery; we transfer the food to the mouth; we masticate food to form a bolus and finally swallow. In other words, humans perform many complex and coordinated oral and body actions during the feeding process. In this context, healthy and young subjects usually do not report any problems in performing the eating process. In contrast, in the elderly population, due to ageing (e.g. muscle weakness or having fewer teeth), some of these capabilities can become less efficient, leading to difficulties of food consumption. However, having elderly status (i.e. > 65 years old according to the definition of WHO) does not necessarily imply the proportionate loss of all of these capabilities. People over 65 years old are clearly a heterogeneous group with different health status, physical and mental needs, as well as abilities and expectations.

In a previous work, the present authors, reviewed a set of tools suitable to characterize the eating process (Laguna and Chen, 2016). Appropriate tools selected were non-invasive and could easily be used by non-medically trained carers. In elderly participants (n=203), hand grip force, finger grip force, biting force, lip sealing pressure, tongue pressure and touch sensitivity were measured (Laguna et al., 2015). The "Eating Capability" was then used to characterise four categories of participants from weakest to strongest with two intermediate groups. To test the functional utility of this classification, participants 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). However, to the author's knowledge, the associations between eating capability and age have not been characterized.

In order to extend those findings, the present work was designed to evaluate if the hypotheses that eating capabilities can be differentiated between different population groups and ageing influences the measurable capabilities of the eating process.

In the present work, two groups of people above and below 65 years of age were tested for their oral physiological and hand manipulation capabilities. Manual manipulation of food is important for opening and removal packaging, arranging and controlling food on the plate (e.g. cutting to an appropriate size) and transporting the food to the mouth. The tongue also plays an important role in food oral manipulation as well as in the swallowing process. As tactile discrimination is necessary to ensure dexterous and precise hand actions and also in the perception of food texture, subjects were also evaluated for their capability of texture discrimination.

2. Experimental designs

2.1 Subjects

The respondents were divided into two main groups:

Below 65 years old: 36 subjects (18 female, 18 male, average age 31±11 years), were recruited from the Leeds university student community and staff.

Over 65 years old: 40 subjects (23 female and 18 male and average age 79±9 years) from community centres and sheltered accommodation through the Neighbourhood Network Scheme in the area of Leeds, participated in the study.

Participation in the study was voluntary. All subjects who agreed to participate in the study received an information sheet, in addition to a verbal explanation of the purposes of the project and what will be involved in the test. Signed consent forms were obtained from all subjects who participated in the test.

Participants were asked about their dental status and they were grouped into: natural, combination (natural teeth and crowns/bridges), denture, edentulous, or wearing top or low denture. Just one of the participants below 65 years old had natural teeth and crown, the remaining members of this group had natural teeth. Regarding participants over 65 years old: 6 had natural teeth, 8 had a combination between natural and crowns, 24 were denture wearers and 2 participants had upper or the lower dentures.

Ethical approval was obtained for all participants from the Faculty Ethics Committee and all test procedures followed the ethical rules and regulations and standards as set by the University of Leeds, UK (MEEC 13-019, MEEC 12-013).

2.2. General muscle strength

2.2.1. Hand grip force

The maximal hand gripping force (kg) of each participant was measured using an adjustable handheld dynamometer (JAMAR dynamometer). This device has variable levels to cater for variation in strength capabilities and is routinely used in clinical studies for rehabilitation of patients with neuromuscular problems (Figure 1a) (Butler *et al.*, 2011).

Following the methodology described by Trampisch et al. (Trampisch *et al.*, 2012), participants were asked to squeeze the hand dynamometer with the maximum effort and maintain this for approximately 3 seconds with each hand (alternately) with the elbow flexed to 90 degrees, forearm and wrist were monitored to maintain a neutral position.

The dynamometer has 5 different positions to accommodate better the hand span, the position selected was with the handle in the second groove (at level 2) being the most appropriate in 70% of the cases considered in previous studies (Trampisch *et al.*, 2012). However, if the participant felt any discomfort to achieve this level the force position was moved to another level at which the participant could achieve maximal grip force.

The intensity of hand grip force was displayed as the maximum force in the digital panel. Three repeats were obtained and an average value was calculated for each hand.

2.2.2. Finger precision grip force

Finger gripping force was measured with a modified version of the device designed by Flanagan et al. (Flanagan *et al.*, 2012). It consists of a built-in thin flexible force transducer (Tekscan, South Boston, Mass) connected to a multimeter (Figure 1b.1), two self-adhesive 1cm diameter neoprene disc were attached to the sensor to make the measurement comfortable for participants. The flexforce transducer is a very thin flexible sensor to measure forces between 2 compressing solid substrates (Flanagan et al., 2012).

The multimeter connected to the flexisensor registered the resistance in Ohms (Ω). The resistance in the sensor depends directly on the applied force load. It decreases to a stable minimum with the increasing load until a steady maximum force is applied. To convert the registered resistance data into force values, a calibration was conducted for the equipment. Forces from 5 N to 250N were applied using a texture analyser (TA-XT.plus Texture Analyzer equipped with the Texture Exponent software version 2.0.7.0. Stable Microsystems, Godalming, UK) and associated resistance at each applied force was recorded. Therefore, a standard curve of the applied force (N) and registered resistance was produced.

To perform the finger gripping test, subjects were asked to squeeze the neoprene disc between thumb and index finger. The minimum resistance value was recorded and the test was repeated in triplicate for each hand.

2.2.3. Maximum isometric tongue pressure

Tongue muscle strength was measured in previous studies using the Iowa Oral Performance Instrument (IOPI®) (Alsanei and Chen, 2014) (Figure 1c). It is a medical device initially developed for the clinical assessments of rehabilitation patients. A disposable tongue bulb is connected to a pressure transducer with a thin plastic tube to record tongue pressure (Ono et al. 2009). Participants were asked to locate the bulb into the centre of the oral cavity between the tongue and the hard palate and to exert maximal tongue pressure. The test was performed in triplicate with a brief rest given between the tests.

2.3.Tactile threshold

In contrast to other sensory attributes (e.g. taste, aroma and colour), there are no single and specific receptors for texture because of its multiparameter nature (Szczesniak, 2002).

For this reason, the capability of an individual to discriminate textural features is difficult to quantify. In this work, a combination of two different approaches was used: tactile sensitivity threshold and gel strength discrimination.

2.3.1. Tactile sensitivity threshold

Tactile sensitivity was assessed using the Semmes-Weinstein Monofilament (SWM) test (Figure 1d) (Wiggermann *et al.*, 2012). This test has been traditionally used to measure recovery of sensibility (Bell-Krotoski *et al.*, 1993) and it has been used for tactile discrimination by the present authors (Aktar *et al.*, 2015b, a).

It consists in a series of 20 flexible calibrated nylon monofilaments of equal length and varying diameters (0.06-1.14 mm). The monofilament is pressed against the skin showing a bowed deflection for 1 second, creating a pressure of between 0.045g mm^{-2} to 447g mm^{-2} (Meirte *et al.*, 2015) with the amount of pressure applied being dependent on the monofilament and not the examiner (Bell-Krotoski *et al.*, 1993).

This was measured at the dominant index finger tip and the front tip of the tongue.

Finger: In this study subjects were blindfolded and asked to rest their hand on the bench and extend fingers in a relaxed manner. A Touch Sense™ monofilament was pressed perpendicularly to the skin surface until the filament achieved a bowed deflection for approximately 1.5 seconds and then removed. Monofilament which applied a force of 300 g was used first as a demonstration of how the test is conducted. Formal tests started with a monofilament of 10 g force and then continued with another monofilament in descending sequential order.

Then, the subject was asked: *Can you feel the monofilament?* Participants were instructed to answer "Yes/No". The value of the last monofilament that was detected by the participant was recorded as the touching threshold which is then taken as an indication of threshold sensitivity.

*Tongue***:** as in the finger tactile sensitivity, participants were asked: *Can you feel the monofilament?* In this case, subjects were asked to elevate the hand when they could feel the pressure exerted by the monofilament on the tongue surface to indicate as a positive answer. The last monofilament which the participant was able to feel was then noted as the tongue touch sensitivity. Between each test the fibre of the evaluators was cleaned using an antibacterial wipe.

2.3.2. Gel stiffness

Gels were made using carrageenan and locust bean gum (Vege-gel, Dr. Oetker), in eight different concentrations (1.7, 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1%). Gel was dissolved and stirred in water at 80 ^{0}C. When the powder was completely dissolved, it was transferred to a plastic ice tray. All the samples were then refrigerated at 4 ^{0}C.

Gel firmness (or hardness) was measured using a compression test with a test speed of 2 mm s^{-1} and a trigger force of 3 g. Each test was conducted on five replicates of each formulation. Samples were compressed up to 20% of the initial dimension, tests were conducted in 75 mm-diameter aluminium plate (P/75). The sample geometry had trapezium configuration (1.8x1.5x1.5 cm). The elastic modulus was calculated as the coefficient of pressure (Pa i.e. force per area) divided by the strain at 20%. Each test was conducted on five replicates of each formulation. Figure 2 shows the elastic moduli for the different gel concentrations. The eight different concentrations (1.7, 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1 %) were chosen for gel preparation that correspond to the following gel firmness: 26.9, 28.0, 29.9, 32.2, 35.1, 38.5, 42.5, 47.0 kPa. Tests were performed using the texture analyzer as described previously.

The discrimination test was applied in a pairwise comparison between each sample and the reference sample (1.7%). Participants were asked to compress from left to right the two gels with the index finger. Participants were asked the following: *Is there any difference between these samples? Why is it different?* To determine a recognition or identification threshold, that is, the level at which a stimulus can not only be detected but also be recognised. Tests were conducted with increasing differential hardness between the samples and a decisive response of perception was obtained.

When the participant was able to correctly detect the difference in firmness for two consecutive pairs, the gel firmness difference between the first pair was taken as the discriminating capability of the subject.

In order to evaluate the gel stiffness results statistically, we employ the Weber´s fraction. Here, the fraction ($\Delta I/I = k$) describes the change in intensity to a physical stimulus in order to be just perceivably different to a constant ratio, and is generally used as an index of how well the sensory system detects changes (Lawless and Heyman 2010).

2.4.Eating capability score

Eating capability can be defined as the *physical, physiological, and cognitive capabilities of an individual in handling and consuming food.* This work mainly focussed on the hand tactile discrimination and tongue force capability of two different groups of participants.

To define a relative force capacity for every individual, a ratio was generated with the denominator having the maximum value obtained for the test by the strongest participant, and the numerator was the specific participant's value obtained conducting the test. This provides a relative measure for each individual. For texture discrimination the tactile sensitivity threshold, i.e. the lowest perceived tactile measure was selected (or the most sensitive participant) and was rated a reference score of 1, with all other measured values rated in ratio.

For the gel strength discrimination, the Weber's fraction was utilised and similarly a relative scale was defined, namely, the most sensitive participant was assigned a rating of 1 and a rating of 0 for those participants that could not perceive any difference between any of the samples. For those participants that perceived intermediate values their associated Weber fraction calculation was subtracted from 1 to assign a relative rating to the most sensitive individual.

To date, to the authors' knowledge there are no reference values for measurements of these types of evaluations, therefore, we have adopted the above methodologies which have yielded promising insights into this area of investigation. The authors hope that this investigation will stimulate further studies in this important area in future research.

The maximum eating capability is defined as a 5-point score having each test measurement contributing a maximum of 1-point (Eq.1).

Equation (1)

$$EC = \frac{\left(\frac{RH_i}{RH_S}\right) + \left(\frac{LH_i}{LH_S}\right)}{2} + \left(\frac{FF_i}{FF_S}\right) + \left(\frac{GD_i}{GD_S}\right) + \left(\frac{TP_i}{TP_S}\right) + \frac{\left(\frac{Tc\ T_i}{TcT_S}\right) + \left(\frac{TcF_i}{TcF_S}\right)}{2}$$

where, RH is the right hand gripping force (kg), LH is the left hand gripping force (kg), BF is the biting force (kg), GD is the gel discrimination, and FF is finger force, TP is the tongue pressure (KPa), TcT is the is the tactile tongue and TcF tactile finger threshold . Subscripts *i* and *S* represent the individual score and strongest individual scoring the highest in that particular test, respectively.

Participants were placed into categories relating to their eating capability. Participants with eating capability less than 1 were placed in cluster 1; participants with eating capability equal or greater than 1 and less than 2, were placed in cluster 2, and so on.

2.4. Data analysis

The mean values and standard deviations (SD) were calculated using Microsoft Office Excel 2010. A two-factor ANOVA with an independent variable: age (two groups: young and elderly) and gender (two groups: males and female) was applied to physical capabilities (force and texture discrimination). ANOVA tests were conducted using SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp) with p=0.05 significance level.

Texture discrimination capability was represented using probit regression analysis with the median response as the threshold value referred to as the population threshold.

In evaluating the texture discrimination capability, that is, tactile sensitivity and gel-strength determination of the survey participants, it is desirable to obtain quantitative response measurements. However, in these cases, responses are binary responses with either 'detect' or 'non-detect' and are dependent upon the strength of the applied stimulus. For a particular subject, under the controlled conditions of the experiment, there will be an intensity level (threshold) below which, no response occurs and above which, a response is noted. The individual detection thresholds will vary between participants and indeed within participants on different occasions under the same test conditions due to uncontrolled internal or external variables. Given those variations in responses we may determine, at a specific magnitude of intensity of the supplied stimulus, the proportion of the population whom successfully detected the stimulus. The distribution of these proportions as measured on the natural scale may be skewed but under a logarithmic transformation become approximately normal and thus amenable to probit regression analysis (Finney, 1971; Meilgaard *et al.*, 2006), as given by equation (2)

$$P = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} dx \qquad \text{equation (2)}$$

Here, x denotes the intensity of the logarithmic of the supplied stimulus, μ the mean of the distribution i.e. log mean stimulus intensity and σ^2 the variance.

A natural consequence of this probit analysis enables the response data to be fitted to the normal variate description and median stimuli to be determined. Stimuli which produce their effects by equivalent methodologies often have equal variances of their log threshold values for a sample population despite having different median estimates. In the present study, we used median response as the threshold value referred to as the population threshold (Lawless and Heymann, 1998). Based on this approach, the graphs of tactile sensitivity threshold and gel discrimination threshold were plotted with probit data analysis, which is log-normalisation regression analysis that shows the best fit and permits estimation of the median value.

Pearson's correlation of the measured parameters was analysed using XLSTAT software (Microsoft, Mountain View, CA).

3. RESULTS and DISCUSSION

3.1. Muscle strength

Hand and finger force

Figure 3 presents the ratio of values of hand and finger grip force for each participant against their age.

Hand grip force results: In this test, the force is delivered by the whole hand since the hydraulic dynamometer may be fully encompassed using the thumb as a buttress and the long flexors and extensors may impart significant force. On average, participants over 65 years were able to produce a force of 16.87±10.84 kg and participants below 65 years could produce nearly double the force having hand compression, 30.26±7.35 kg.

This level of reduction of hand force with age is in agreement with previously published findings (Frederiksen *et al.*, 2006; Chen *et al.*, 2014). Furthermore, this loss of strength with ageing correlates with a loss of function since strength is an important component in performing daily activities (Grabiner and Enoka, 1995)

Hand force is also influenced by gender (Gentil and Tournier, 1998), with elderly women having the lowest value (11.50±4.46 kg vs 26.07±4.00 kg in elderly men, 24.12±9.59 kg in young women and 37.56±7.75 kg for young men).

Finger precision grip in terminal position: In this test, the sensor is held between the thumb and index finger. The small muscles of the hands are involved (as well as the flexors digitorum profundus and superficials, and pollicis longus), with the strength of contraction being much less than that reported using the whole hand. For this reason, and in comparison with the hand grip, the finger grip force is lower than the hand grip force for all subjects. The weakest finger force grip was registered for elderly women (0.854±0.034 kg) followed by elderly men (2.073±1.714 kg), young women (2.459± 0.874 kg) and the strongest group, the young men (3.859±1.3040 kg). The strongest individual value was reported by a young male participant (6.35 kg). The finger precision grip has the highest tactile capacity of all of the precision grips tested (i.e. the subterminal opposition as in the holding of a pen), and is most easily disrupted in traumas or disease (e.g. arthritis) of the hand (Palastanga, 2012) as well as integrity of sensorimotor system, absent in Parkinson's disease or Huntington's disease (Hermsdörfer *et al.*, 2003). The decrease in the muscle strength capability with the age can be observed for the two age groups (Figure 3), being in accordance with previous studies that reported a linear correlation between age and the hand force for healthy adults (Budziareck *et al.*, 2008). As shown in figure 3, although some subjects in the elderly group are capable of exerting high hand force, nonetheless, a decrease in finger force capability is observed.

Tongue pressure

In figure 4 the maximum tongue pressure against age and gender are shown. The tongue pressure decreased significantly with the age (p-value <0.05). In contrast, the correlation between tongue pressure and gender was not statistically significant (p > 0.05).

The tongue pressure shows that participants over 65 years were capable of exerting less tongue force in comparison with the younger age group. This is in agreement with the findings of Ueda *et al.*(2004) whom also reported that a disorder of the tongue provoked difficulties in eating and swallowing, and which is a frequent problem encountered in the elderly population ((Palmer *et al.*, 2000), (Zargaraan *et al.*, 2013), making them more susceptible to swallowing disorders.

As the results suggest, strength capabilities vary between individuals and decrease with age. Previous authors reported that at adult age, skeletal muscle strength is relatively stable until the age of 40 years, after which a decrease in muscle strength is observed (Deurenberg P., 2009).

3.2.Texture discrimination capability

Tactile sensitivity threshold

Figure 5 illustrates the normal cumulative distribution fit for touch sensitivity thresholds using Semmes-Weinstein Monofilament from 62 participants: 35 participants below 65 years and 27 participants older than 65 years of age. Those participants not able to feel the 300g monofilament have not been included in the results because their tactile threshold cannot be detected by Touch Sense™ monofilament.

These results are in agreement with previous research (Decorps *et al.*, 2014) where the effect of ageing on tactile transduction process was also studied. In their work, the authors explained how with age, a combination of several changes in tactile detection, nerves transmission and skin changes contribute to the reduction of tactile sensitivity.

Finger sensitivity. In figure 5a results reveal that a young population (< 65 years) had lower finger touch threshold (0.039 g for the 50th % of the population) in comparison with the population ≥ 65 years which had the highest finger touch threshold (0.147 g for the 50th % of population).

Tongue sensitivity. Figure 5b shows the tongue threshold sensitivity for both populations. In agreement with the finger sensitivity threshold, young participants had lower thresholds (mean= 0.022 g), in comparison with people over 65 years (mean= 0.065 g).

It is well reported in literature that the fingers and tongue have different tactile sensitivities. In figure 5a) and b) a comparison between the thresholds may be noted, with the tongue exhibiting a higher sensitivity. Strassburg et al. (Strassburg *et al.*, 2009) cited that the oral mucosa (at tongue) and glabrous skin (at finger) contain the same neurological "equipment", except for the absence of the Pacinian corpuscles in the oral mucosa. Strassburg *et al* evaluated finger-palm and tongue-palate compressions having different discrimination thresholds for discs and with differences in thickness and diameter of the sensors used. They postulated that a finger-palm system displayed sensitivity as accurate as the tongue-palate system. In the present study, we have used filaments to exert pressure at different surfaces and not in two positions simultaneously as in the finger-palm or tongue-palate system which may lead the differences noted between the results obtained.

Without sufficient tactile capability, individuals have a predisposition to mechanical, thermal or chemical injury (Birke *et al.*, 2000). The present authors also postulate that high tactile threshold is another factor that reduces eating performance. Although experimental data is needed, a lower sensation at the fingers can result in a reduced accuracy in hand movements, in the same way, lower sensation in the mouth can be associated with a reduced ability by the tongue for food manipulation and discrimination and, consequently a reduced enjoyment of food. This is partially due to the need to accurately sense food mechanical properties in order to masticate and swallow safely (Engelen et al. 2005).

In none of the measurements described differences in gender were found (data not shown).

Threshold of gel discrimination

For this test, the results of the 70 participants (36 older, 34 young) have been analysed and are presented in figure 6. In this pair-comparison test, individuals had the opportunity to exert compressions in the different gels presented. These results reveal that, in comparison with elderly participants, young participants had better discrimination skills; they were able to discriminate between small differences in gel strength.

Gel strength discrimination implies a precise regulation of grip forces. To exert the force with the index finger, an individual has to anticipate the physical properties of the gel. Participants were asked firstly to compress and secondly to break the gels. Researchers observed that most of the elderly participants were not able to perform these two tasks separately, with gels being broken without previous compression. This is clear evidence that the elderly lacking finger coordination and control of force application.

3.3. Influence of age and gender in the measured capabilities

In this work we have assessed how age and gender influence different force, capabilities of the hand, finger and tongue. All results are summarized in table 1a.

It can be observed how both gender and age influence recorded forces. To investigate the association two-way ANOVA was performed including the texture discrimination threshold. In table 1b it can be observed that both gender and age have a significant effect on hand force (right and left) and finger force, with gender having a greater influence in the hand forces than age group. However, for other forces measured, age has more influence. For the tongue force, gender has no significant influence, in contrast with age. The same age effect was observed by the gel discrimination threshold and for the touching force tongue threshold; as age has a strong effect whilst gender seems not to have any influence. Touching force finger threshold did not show any significant effect in relation to gender and age group, probably due to the high variability among the participants.

3.4. Relation between measured parameters

In the present work, the association between the measured parameters was investigated as shown in table 2. Age, as has been discussed, is correlated with all the parameters measured. Hand grip, finger grip and tongue force were correlated negatively with age (-0.671,-0.684, and -0.746 respectively). Tongue and gel discrimination threshold were correlated positively (0.351 and 0.679 respectively). In other words, with age a decrease in muscular force and sensitivity is observed. The causative reason is probably due to the ageing process which may cause 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 et al., 2003)

Many authors have reported that in the elderly population the hand grip strength is a predictor of overall muscular strength (Chen *et al.*, 2014), health (Norman *et al.*, 2011) and is consistently associated, among other things, with a greater probability of premature mortality (2007).

In the present study, hand force showed a positive correlation with finger force (0.779) and tongue pressure (0.619). To the author's knowledge, there are no previous studies which have investigated this relation with regards to the eating process. Gentil and Tournier (1998) studied the fine control of forces in articulatory organs (tongue, lips) and fingers, finding differences in the precision of movement execution. In the present study we believe that in the absence of sensory motor illness, hand force could provide predictive information about the tongue force capability during food oral consumption. Although finger grip force is highly correlated with hand grip force, finger grip is associated with highly skilled motor performance (Hermsdörfer *et al.*, 2003) and not with the overall muscular strength as in the hand grip force, providing more information on the tactile ability of the individual. As such, individuals with low hand grip force and low finger grip force will also be the most likely to exhibit the weakest and the least coordinated performance.

Finger tactile sensitivity was not correlated significantly ($p>0.05$) with any of the other measures. Also, there is a negative correlation between hand force/finger force and firmness sensation (-0.503).

Butler et al (Butler *et al.*, 2011) hypothesized that tongue strength may be correlated with hand grip strength using similar devices and techniques as used in this study. Unlike the tongue pressure measurement at the central location, the authors measured the tongue force in two different locations inside the oral cavity, namely, the anterior and posterior regions, and noting that only the posterior tongue strength was significantly associated with handgrip strength. In the present study, due to the size and shape of the bulb used, only the tongue pressure was measured in one area of the palate, finding significant positive correlation between hand force and tongue pressure (0.533).

3.4. Eating capability and age

In figure 7 the relation between age and eating capability score has been plotted. As it can be observed there are two discernible clusters corresponding to the population over 65 years old and under 65 years old. However, although there is a significant ($p<0.05$) trend between age and eating capability, it can be seen the high variability in both populations.

In summary of the population, 4 groups of eating capability were formed and are shown in table 3. The strongest and weakest participants, eating capability groups are 5 and 1 respectively, which may be easily differentiated by age. Also, these two extreme groups were considerably different in terms of their force capability and texture discrimination.

4. Conclusions

In this work measurements of physiological capabilities associated with eating (hand, finger and tongue force and touch sensitivity) have been conducted for two different groups, young adults (< 65 years) and elderly adults (> 65 years). It has been shown how age correlates with the muscular capability actions, revealing less strength (at hand and tongue) and less coordination to exert certain specific movements (finger grip force). According to the results presented, the most vulnerable group is elderly women. Other parameters related to the eating process have also been measured such as touch sensitivity and gel strength discrimination. These results suggest that having old age can be correlated with a decline in touch sensory abilities and that further this is not specific to gender. These facts suggest a reduction in hand strength and coordination and in the manipulation of food and food packaging, and a loss of food enjoyment as a consequence of lack of texture perception.

Additionally, although it is recognised more substantial research is needed with larger samples, our results provide further support to the hypothesis that the eating capability concept and its measurable parameters are reliable indicators for assessing individual feeding abilities and thus offer an additional and valuable diagnostic method to assess vulnerable and senior age-grouped individuals. In future work, we aim to consider larger and diverse samples, for example, participants of the same age but with physiological differences such as different dental condition, different saliva excretion, etc. Also, the authors would like to study the dietary patterns (frequency of different consistency food) of individuals to assess if eating capability can help us to understand consumption behaviour, food choices and preferences.

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Conflict of Interests

The authors declare that they do not have any conflict of interest.

Ethical Review

This study was approved by Faculty Ethics Committee at the University of Leeds (MEEC 13-019, MEEC 12-013).

Informed Consent

Written informed consent was obtained from all study participants

References

2007. 13th Annual Meeting of the Organization for Human Brain Mapping (2007). NeuroImage *36, Supplement 1*, S1-S125.

AKTAR, T., CHEN, J., ETTELAIE, R., and HOLMES, M. 2015a. Evaluation of the Sensory Correlation between Touch Sensitivity and the Capacity to Discriminate Viscosity. Journal of Sensory Studies *30*, 98-107.

AKTAR, T., CHEN, J., ETTELAIE, R., and HOLMES, M. 2015b. Tactile Sensitivity and Capability of Soft‐Solid Texture Discrimination. Journal of Texture Studies *46*, 429-439.

ALSANEI, W.A., and CHEN, J. 2014. Studies of the Oral Capabilities in Relation to Bolus Manipulations and the Ease of Initiating Bolus Flow. Journal of Texture Studies *45*, 1-12.

BELL-KROTOSKI, J., WEINSTEIN, S., and WEINSTEIN, C. 1993. Testing Sensibility, Including Touch-Pressure, Two-point Discrimination, Point Localization, and Vibration. Journal of Hand Therapy *6*, 114-123.

BIRKE, J.A., PATOUT JR, C.A., and FOTO, J.G. 2000. Factors associated with ulceration and amputation in the neuropathic foot. Journal of Orthopaedic & Sports Physical Therapy *30*, 91-97.

BUDZIARECK, M.B., PUREZA DUARTE, R.R., and BARBOSA-SILVA, M.C.G. 2008. Reference values and determinants for handgrip strength in healthy subjects. Clinical Nutrition *27*, 357-362.

BUTLER, S.G., STUART, A., LENG, X., WILHELM, E., REES, C., WILLIAMSON, J., and KRITCHEVSKY, S.B. 2011. The relationship of aspiration status with tongue and handgrip strength in healthy older adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 452-458.

CARMELI, E., PATISH, H., and COLEMAN, R. 2003. The aging hand. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences *58*, M146-M152.

CHEN, X.-P., LU, Y.-M., and ZHANG, J. 2014. Intervention study of finger-movement exercises and finger weight-lift training for improvement of handgrip strength among the very elderly. International Journal of Nursing Sciences *1*, 165-170.

DEAN, M., RAATS, M. M., GRUNET, K. G. 2009. Older people, food and satisfaction with life In *Food for the ageing population*. M. Raats, Groot, L. D. , ed. Woodhead Publishing Limited and CRC Press LLC, FL,USA.

DECORPS, J., SAUMET, J.L., SOMMER, P., SIGAUDO-ROUSSEL, D., and FROMY, B. 2014. Effect of ageing on tactile transduction processes. Ageing Res Rev *13*, 90-99.

DEURENBERG P., D.-Y.M. 2009. Ageing and changes in body composition: the importance of valid measurements. In *Food for the ageing population.* . M.R.a.L.d. Groot., ed. Woodhead Publishing Limited aned CRC Press LLC, FL, USA.

FILLION, L.K., D. . 2003. Food texture and eating difficulties in the elderly. Food Industry Journal *4*, 27-33.

FINNEY, D.J. 1971. *Probit Analysis: 3d Ed*. Cambridge University Press.

FLANAGAN, D., ILIES, H., O'BRIEN, B., MCMANUS, A., and LARROW, B. 2012. Jaw Bite Force Measurement Device. Journal of Oral Implantology *38*, 361-364.

FONTIJN-TEKAMP, F., SLAGTER, A., VAN DER BILT, A., HOF, M.V.T., WITTER, D., KALK, W., and JANSEN, J. 2000. Biting and chewing in overdentures, full dentures, and natural dentitions. Journal of Dental Research *79*, 1519-1524.

FREDERIKSEN, H., HJELMBORG, J., MORTENSEN, J., MCGUE, M., VAUPEL, J.W., and CHRISTENSEN, K. 2006. Age Trajectories of Grip Strength: Cross-Sectional and Longitudinal Data Among 8,342 Danes Aged 46 to 102. Annals of Epidemiology *16*, 554-562.

GENTIL, M., and TOURNIER, C.L. 1998. Differences in fine control of forces generated by the tongue, lips and fingers in humans. Arch Oral Biol *43*, 517-523.

GRABINER, M.D., and ENOKA, R.M. 1995. Changes in movement capabilities with aging. Exercise and sport sciences reviews *23*, 65-104.

HERMSDÖRFER, J., HAGL, E., NOWAK, D.A., and MARQUARDT, C. 2003. Grip force control during object manipulation in cerebral stroke. Clinical Neurophysiology *114*, 915-929.

LAGUNA, L., and CHEN, J. 2016. The eating capability: Constituents and assessments. Food Quality and Preference *48, Part B*, 345-358.

LAGUNA, L., SARKAR, A., ARTIGAS, G., and CHEN, J. 2015. A quantitative assessment of the eating capability in the elderly individuals. Physiology & behavior *147*, 274-281.

LAWLESS, H.T., and HEYMANN, H. 2000. *Sensory evaluation of food: principles and practices*. Chapman and Hall, New York, NY.

MAITRE, I., VAN WYMELBEKE, V., AMAND, M., VIGNEAU, E., ISSANCHOU, S., and SULMONT-ROSSÉ, C. 2014. Food pickiness in the elderly: Relationship with dependency and malnutrition. Food Quality and Preference *32, Part B*, 145-151.

MEILGAARD, M.C., CARR, B.T., and CIVILLE, G.V. 2006. *Sensory evaluation techniques*. CRC press.

MEIRTE, J., MOORTGAT, P., TRUIJEN, S., MAERTENS, K., LAFAIRE, C., DE CUYPER, L., HUBENS, G., and VAN DAELE, U. 2015. Interrater and intrarater reliability of the Semmes Weinstein aesthesiometer to assess touch pressure threshold in burn scars. Burns *41*, 1261-1267.

MIYAURA, K., MORITA, M., MATSUKA, Y., YAMASHITA, A., and WATANABE, T. 2000. Rehabilitation of biting abilities in patients with different types of dental prostheses. Journal of oral rehabilitation *27*, 1073-1076.

MOJET, J., CHRIST-HAZELHOF, E., and HEIDEMA, J. 2005. Taste perception with age: pleasantness and its relationships with threshold sensitivity and supra-threshold intensity of five taste qualities. Food Quality and Preference *16*, 413-423.

NORMAN, K., STOBÄUS, N., GONZALEZ, M.C., SCHULZKE, J.-D., and PIRLICH, M. 2011. Hand grip strength: Outcome predictor and marker of nutritional status. Clinical Nutrition *30*, 135-142.

PALASTANGA, N., FIELD, D., SOAMES, R. . 2012. *Anatomy and Human Movement. Structure and Function.* Elsevier, Churchill Livingstone, UK.

PALMER, J.B., DRENNAN, J.C., and BABA, M. 2000. Evaluation and treatment of swallowing impairments. Am Fam Physician *61*, 2453-2462.

POPPER, R., KROLL, B. J. 2003. Food Preference and consumption among the elderly. Journal of Food Technology *57*, 32-40.

SCHIFFMAN, S.S., and ZERVAKIS, J. 2002. Taste and smell perception in the elderly: Effect of medications and disease. In *Advances in Food and Nutrition Research*. Academic Press, pp. 247-346.

STRASSBURG, J., BURBIDGE, A., and HARTMANN, C. 2009. Identification of tactile mechanisms for the evaluation of object sizes during texture perception. Food quality and preference *20*, 329-334.

SZCZESNIAK, A.S. 2002. Texture is a sensory property. Food Quality and Preference *13*, 215-225.

TRAMPISCH, U.S., FRANKE, J., JEDAMZIK, N., HINRICHS, T., and PLATEN, P. 2012. Optimal Jamar dynamometer handle position to assess maximal isometric hand grip strength in epidemiological studies. The Journal of hand surgery *37*, 2368-2373.

WIGGERMANN, N.E., WERNER, R.A., and KEYSERLING, W.M. 2012. The Effect of Prolonged Standing on Touch Sensitivity Threshold of the Foot: A Pilot Study. PM&R *4*, 117-122.

WODA, A., FOSTER, K., MISHELLANY, A., and PEYRON, M. 2006. Adaptation of healthy mastication to factors pertaining to the individual or to the food. Physiology & Behavior *89*, 28-35.

ZARGARAAN, A., RASTMANESH, R., FADAVI, G., ZAYERI, F., and MOHAMMADIFAR, M.A. 2013. Rheological aspects of dysphagia-oriented food products: A mini review. Food Science and Human Wellness *2*, 173-178.

Table 1. Age and gender influence on the measured parameters

1a. Mean of all the forces measured by age and gender

		Number of participants(n)	Age (years)	Hand force (right) (kg)	Hand force (left)(kg)	finger force (dominant hand) (kg)	Tongue pressure (kPa)
young	Women	19	28.79[a] (6.06)	24.12[ab] (8.58)	22.19[c] (9.40)	2.46[b] (0.86)	56.59[b] (8.97)
	Men	16	28.88[a] (8.85)	37.56[c] (7.75)	36.03[b] (7.58)	4.05[c] (1.12)	54.24[b] (14.36)
elderly	Women	24	82.42[c] (8.37)	11.50[a] (4.46)	12.15[a] (10.00)	0.84[a] (0.33)	27.58[a] (13.28)
	Men	14	74.79[b] (7.58)	26.07[ab] (9.59)	23.02[b] (8.80)	2.31[b] (1.91)	34.58[a] (14.56)

Values in parenthesis are standard deviations. Means in the same column with the same letter do not differ significantly (p>0.05) according to Tukey's test.

1b. F and p-value (at 0.05) of two-way ANOVA independent variable: age (two groups: young and elderly) and gender (two groups: males and female).

	Dependent Variable					
	Gender		Age group		Gender * Age group	
Dependent Variable	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
Hand force (right)	**61.073**	**0.0001**	**45.285**	**0.0001**	0.099	0.754
Hand force (left)	**32.033**	**0.0001**	**27.896**	**0.0001**	0.463	0.499
Finger force	**34.325**	**0.0001**	**41.436**	**0.0001**	0.047	0.829
Tongue force	0.574	0.451	**63.060**	**0.0001**	2.331	0.131
Gel discrimination threshold	0.026	0.873	**33.184**	**0.0001**	0.001	0.981
Touching force finger threshold	1.612	0.209	1.741	0.191	1.610	0.209
Touching force tongue threshold	0.857	0.358	**18.432**	**0.0001**	0.874	0.353

Table 2. Correlation matrix (Pearson) with the measured parameters and age and its correspondent p value

Correlation matrix (Pearson):

Variables	Age	Right hand force	Finger force	Gel discrimination threshold	Touching force finger threshold	Touching force tongue threshold	Tongue pressure
Age	**1**	**-0.671**	**-0.684**	**0.679**	0.128	**0.351**	**-0.746**
Right hand force		**1**	**0.779**	**-0.503**	0.007	**-0.311**	**0.619**
Finger force			**1**	**-0.549**	-0.139	-0.251	**0.486**
Gel discrimination threshold				**1**	0.241	**0.379**	**-0.482**
Touching force finger threshold					**1**	-0.021	0.065
Touching force tongue threshold						**1**	**-0.368**
Tongue pressure							

Values in bold are different from 0 with a significance level alpha=0.05

p-values:

Variables	Age	Right hand force	Finger force	Gel discrimination threshold	Touching force finger threshold	Touching force tongue threshold	Tongue pressure
Age	**0**	**0.001**	**0.001**	**0.001**	0.327	**0.006**	**0.001**
Right hand force		**0**	**< 0.0001**	**< 0.0001**	0.955	**0.015**	**< 0.0001**
Finger force			**0**	**< 0.0001**	0.285	0.051	**< 0.0001**
Gel discrimination threshold				**0**	0.062	**0.003**	**< 0.0001**
Touching force finger threshold					**0**	0.872	0.620
Touching force tongue threshold						**0**	**0.003**
Tongue pressure							**0**

Values in bold are different from 0 with a significance level alpha=0.05

Table 3. Group segregation in function of eating capability described by individual objective capabilities

Eating capability (group)	Number of participants	age	Hand force (right) (kg)	Hand force (left) (kg)	Finger force (kg)	Gel discrimination threshold	Touching force finger threshold	Touching force tongue threshold	Tongue force (kg)
1.00	5	86.20[a] (10.26)	9.47[a] (4.00)	4.30[a] (5.27)	0.73[a] (0.20)	222.60[a] (83.63)	1.76[a] (1.27)	2.15[a] (1.82)	18.13[a] (7.68)
2.00	22	79.23[a] (13.57)	12.34[a] (5.28)	12.20[b] (4.86)	0.89[a] (0.50)	144.05[a] 9(6.03)	13.77[a] (63.93)	0.31[b] (0.58)	29.21[a] (14.33)
3.00	25	42.92[b] (22.44)	23.68[b] (5.57)	21.27[c] (6.19)	2.29[b] (1.02)	66.08[ab] (75.44)	0.08[a] (0.11)	0.74[ab] (1.39)	47.81[b] (14.38)
4.00	16	41.50[b] (20.42)	34.69[c] (6.30)	36.18[d] (6.81)	3.88[c] (1.36)	38.00[bc] (24.16)	0.05[a] (0.04)	0.27[b] (1.00)	52.83[b] (10.59)
5.00	5	24.60[b] (4.72)	46.83[d] (6.37)	42.26[d] (4.27)	4.35[c] (1.38)	35.40[c] (23.45)	0.01[a] (0.00)	0.01[b] (0.01)	63.12[b] (15.52)

Means in the same column with the same letter do not differ significantly ($p>0.05$) according to Tukey's test. Values in parentheses are standard deviation.

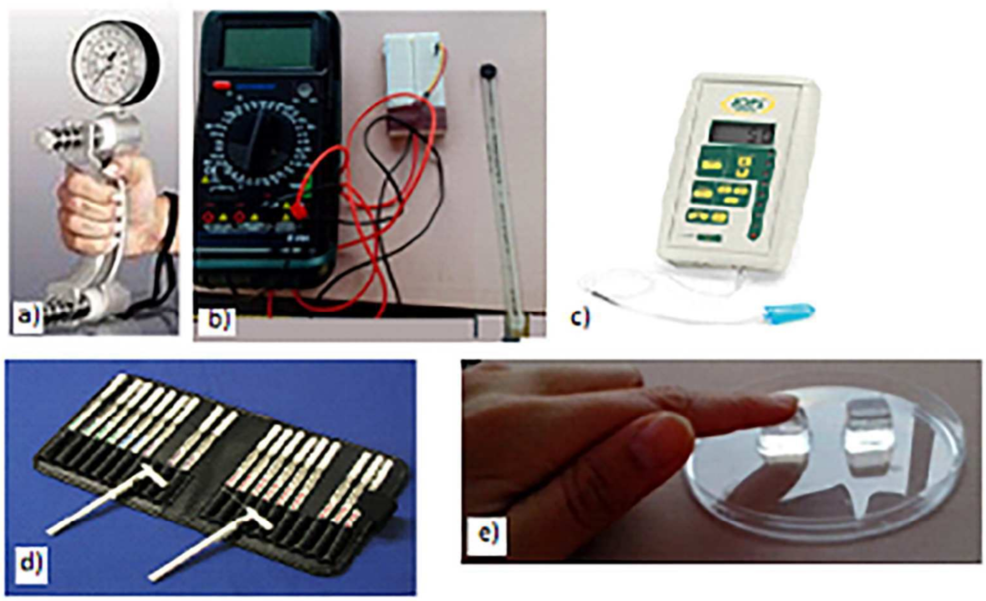

Figure 1. Devices used for the different test carried out a) device used to measure the hand grip force (JAMAR dynamometer), b) device to measure finger grip force (multimeter and flexisensor), c) devices to measure the tongue pressure Iowa Oral Performance Instrument, d) kit used to measure the tactile sensitivity Semmes-Weinstein Monofilament (SWM), e) example of the pairwise comparison to determine the gel discrimination threshold
127x79mm (300 x 300 DPI)

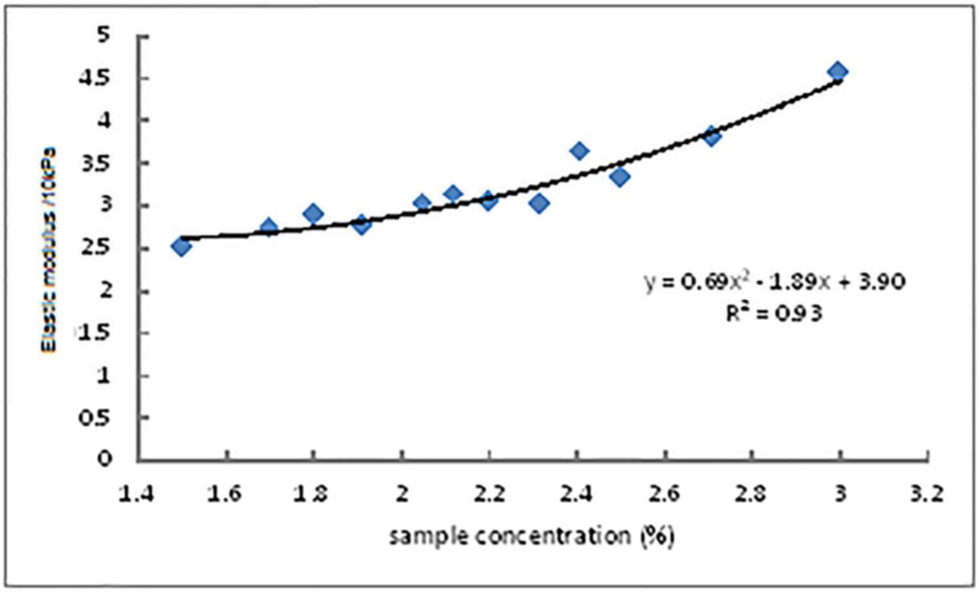

Figure 2. Elastic modulus calculated for the different sample concentrations.
63x39mm (300 x 300 DPI)

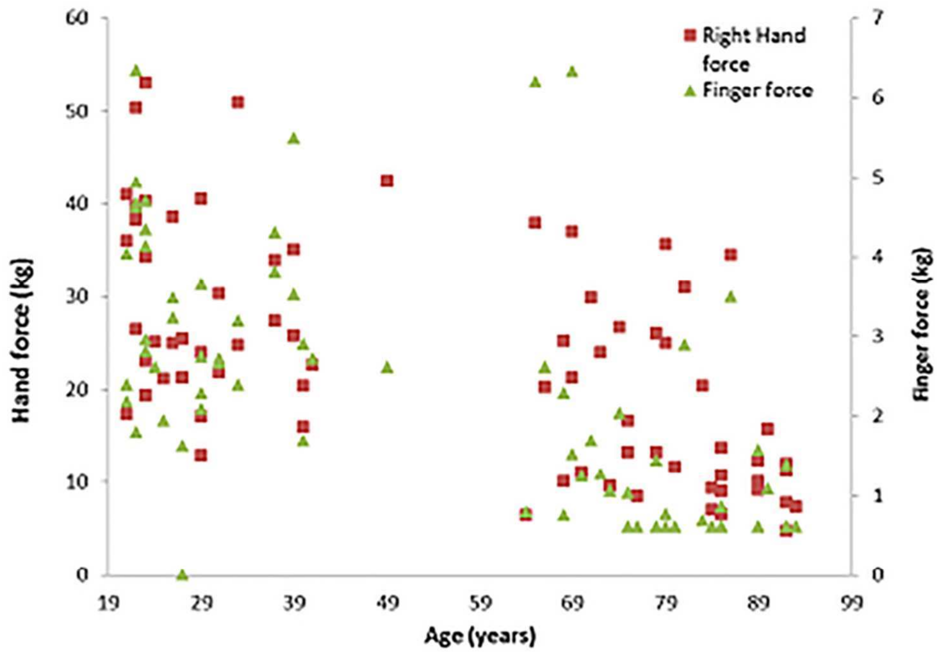

Figure 3. Relation between right hand grip fore (measure with JAMAR dynamometer) and finger grip force (measured with flexi force sensor connected to a multimeter) for each participant
68x46mm (300 x 300 DPI)

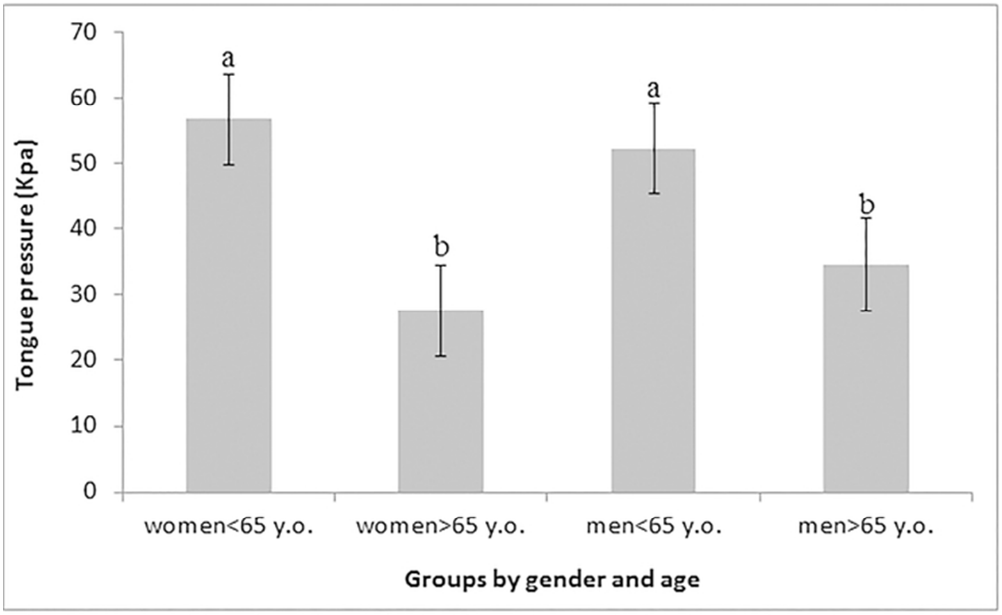

Figure 4. Average of tongue maximum pressure (measured by IOPI device) per age group and gender. Error bars represent the standard deviation, average with the same letter do not differ significantly (p<0.05) according to Tuckey's test
62x38mm (300 x 300 DPI)

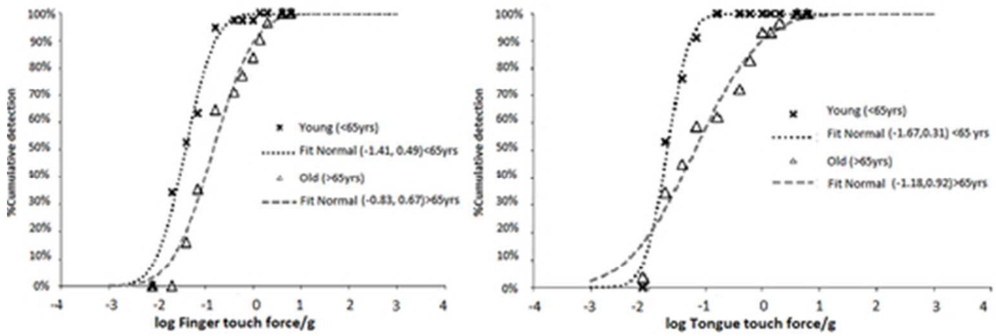

Figure 5a. Normal cumulative distribution of subjects shown as population percentage in detecting the touching force by the finger
Figure 5b. Normal cumulative distribution of subjects shown as population percentage in detecting the touching force by the tongue

44x15mm (300 x 300 DPI)

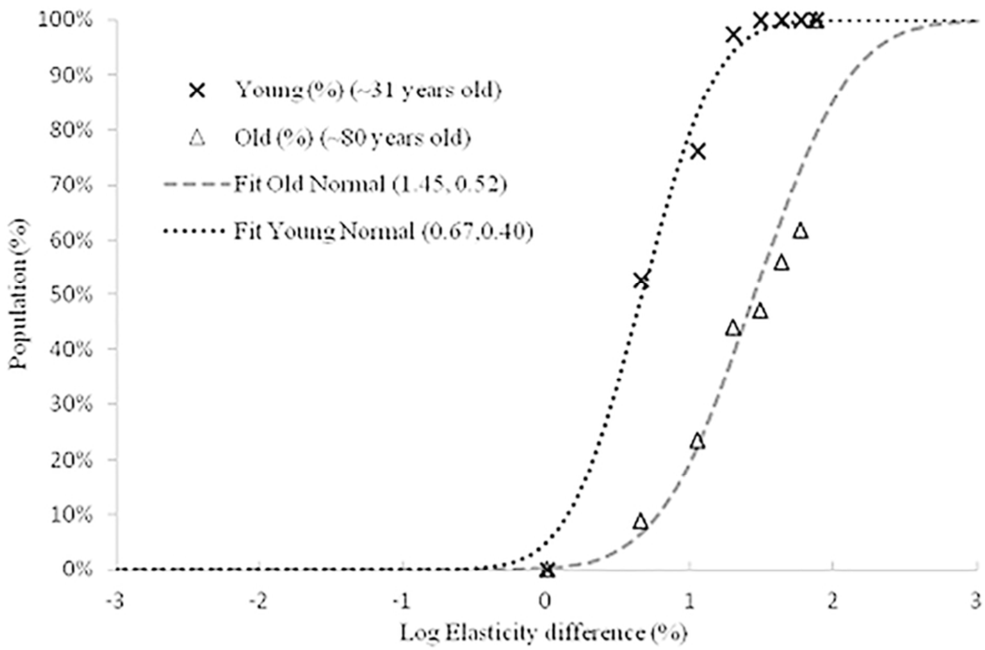

Figure 6. Cumulative response of subjects shown as population percentage in detecting gels elasticity difference
67x45mm (300 x 300 DPI)

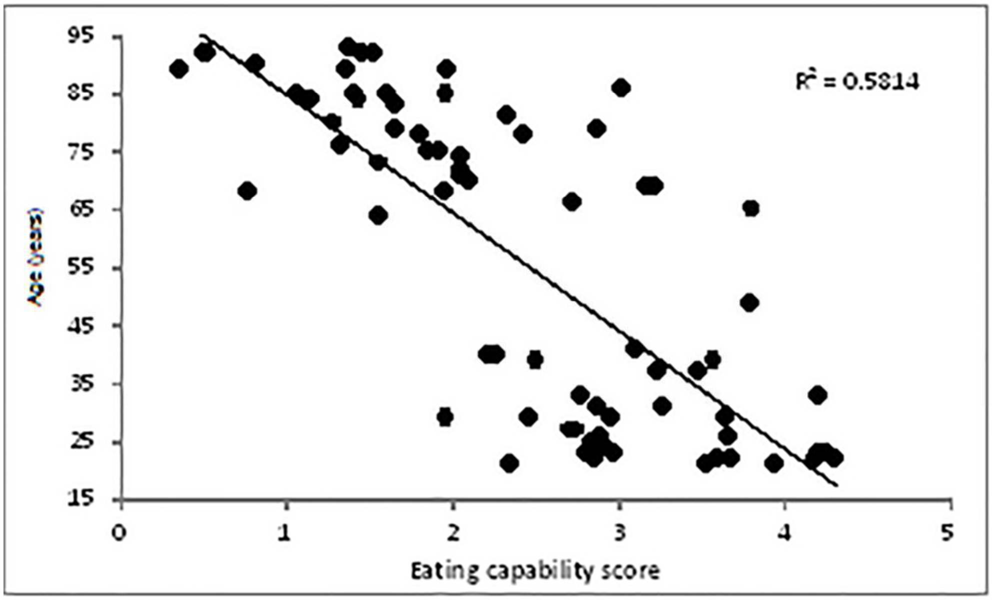

Figure 7. Relation between the age and the eating capability score
63x39mm (300 x 300 DPI)