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Effect of cross-cultural differences on thickness, firmness and sweetness sensitivity

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ABSTRACT

Sensitivity of the somatosensory system may be influenced by multiple physiological parameters. Variations in oral physiology can arise from cross-cultural differences which may potentially affect sensory sensitivity. The aim of this case study was to quantify texture and taste sensitivity in Dutch (Caucasian) and Chinese (Asian) adults living in the Netherlands. Eighty-five healthy subjects were recruited including 44 Dutch (Caucasian) adults (29 females, 22.8 ± 2.3 yrs) and 41 Chinese (Asian) adults (30 females, 24.5 ± 2.1 yrs) living in the Netherlands for less than 1 year. Three sets of stimuli were used to quantify sensitivity of thickness (maltodextrin solutions differing in viscosity), firmness (agar gels differing in fracture stress) and sweetness (sucrose solutions differing in concentration). The 2-Alternative Forced Choice (2-AFC) ascending staircase method was used to determine texture and taste sensitivity. Unstimulated and stimulated saliva flow rate, fungiform papillae density (FPD), lingual tactile threshold and PROP taster status were determined and are referred to as physiological and sensory consumer characteristics. No significant differences were observed between Chinese and Dutch adults for thickness (Dutch 2.60 mPas, Chinese 2.19 mPas), firmness (Dutch 10.5 kPa, Chinese 10.3 kPa) and sweetness sensitivity (Dutch 0.012 g/mL, Chinese 0.017 g/mL). No significant differences were observed between Chinese and Dutch adults for saliva flow rate, lingual tactile threshold and PROP taster status. The relationships between the three sensory sensitivities (thickness, firmness, sweetness) and five physiological and sensory consumer characteristics (unstimulated and stimulated saliva flow rate, FPD, lingual tactile threshold, PROP taster status) were analyzed. Only one out of 15 relationships, firmness sensitivity and FPD, was significantly and weakly related suggesting that inter-individual variation in these consumer characteristics is almost unrelated to sensory sensitivity. We conclude that in this case study thickness, firmness and sweetness sensitivities do not differ between Dutch and Chinese adults living in the Netherlands. Saliva flow rate, fungiform papillae density, lingual tactile threshold and PROP taster status do not explain inter-individual variation in sensory sensitivity between these consumers.

1. Introduction

Consumers show large variation in oral physiology and anatomy depending on age, gender and ethnicity (Ketel, De Wijk, De Graaf, & Stieger, 2020). It has been suggested that oral physiological parameters determine sensory sensitivity of consumers, such as detection and discrimination thresholds for texture and taste properties of foods (Nachtsheim & Schlich, 2013; Yackinous & Guinard, 2001). Changes in sensory sensitivity can lead to inadequate dietary behavior and consequently increase risk of malnutrition (Schiffman, 1993). Decreased sensory sensitivity can lead to increased consumption of sodium or sugar increasing risk of hypertension and diabetes mellitus (Rolls, 1999). Simpson et al. compared taste acuity in elderly in several European countries (Simpson et al., 2012). Age, gender and country of living were main predictors of taste acuity while each of these predictors influenced taste acuity differently depending on taste modality.

During ageing, texture (Kremer, Bult, Mojet, & Kroeze, 2007), taste and smell sensitivity (Cowart, Yokomukai, & Beauchamp, 1994; Methven, Allen, Withers, & Gosney, 2012; Mojet, Christ-Hazelhof, & Heidema, 2001; Stevens, Cruz, Marks, & Lakatos, 1998; Wiriyawattana, Suwonsichon, & Suwonsichon, 2018) are well-known to decline. Several studies reported that females have higher taste sensitivity than males

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(Ahne, Erras, Hummel, & Kobal, 2000; Gudziol & Hummel, 2007; Hyde & Feller, 1981; Landis et al., 2009; Michon, O'Sullivan, Delahunty, & Kerry, 2009; Pingel, Ostwald, Pau, Hummel, & Just, 2010). However, few studies did not find differences in taste sensitivity between genders (Chang, Chung, Kim, Chung, & Kho, 2006; James, Laing, & Oram, 1997). Very little is known about the influence of ethnicity, cross-cultural background or country of living on taste and texture sensitivity. Ethnicity is known to influence oral processing behavior and sensory perception, possibly affecting sensory sensitivity (Ketel et al., 2019; Pedrotti, Spaccasassi, Biasioli, & Fogliano, 2019). Geographical location has been suggested to influence taste perception. Baharuddin and Sharifudin found differences in sourness sensitivity between Malaysians living at the coast or inlands (Baharuddin & Sharifudin, 2015). However, multiple studies did not find differences in sensory perception between ethnicities (Blancher, Lê, Sieffermann, & Chollet, 2008; Lundgren et al., 1986; Prescott & Bell, 1995; Teo et al., 2018). It is not clear which mechanisms underlie the influence of geographical location, cultural background or ethnicity on taste sensitivity and perception. Differences in dietary habits of consumers belonging to different ethnicities and/or living in different geographical locations can contribute to differences in taste sensitivity and perception (Rozin, Mark, & Schiller, 1981). Sensitivity of the somatosensory system may also be influenced by multiple physiological parameters. Sensory sensitivities of consumers have been related to physiological characteristics, such as saliva flow rate, fungiform papillae density (FPD), and to specific sensory characteristics, such as lingual tactile threshold and 6-n-propylthiouracil (PROP) taster status.

Saliva is known to facilitate oral processing behavior by providing lubrication to foods (Engelen & Van Der Bilt, 2008; Nachtsheim & Schlich, 2013; van Eck et al., 2019) and can influence sensory perception and sensitivity. Saliva flow rate has been related to fat perception of milks (Nachtsheim & Schlich, 2013). Higher FPD has been related to more intense perception of sweetness and creaminess (Hayes & Duffy, 2007), saltiness (Miller & Reedy, 1990), increased liking of coffee (Masi, Dinnella, Monteleone, & Prescott, 2015) and high-fat foods (Duffy & Bartoshuk, 2000). This suggests that inter-individual differences in FPD can contribute to inter-individual differences in sensory perception and liking. Aktar et al. found no correlations between texture sensitivity (firmness of gels and thickness of syrups) and lingual tactile thresholds (Aktar, Chen, Ettelaie, & Holmes, 2015a, 2015b). PROP taster status has been linked to more intensive sweetness and bitterness perception (Bartoshuk, Duffy, & Miller, 1994) and to higher sweetness and bitterness sensitivity (Chang et al., 2006). PROP supertasters have lower lingual tactile thresholds than PROP non-tasters and medium-tasters, indicating higher tactile sensitivity (Yackinous & Guinard, 2001).

Variations in oral physiology can arise from differences in culture and ethnicity which may potentially affect sensory sensitivity. Ethnicity does not seem to influence saliva flow rate (Ketel et al., 2020; Pedrotti et al., 2019; Santagiuliana et al., 2019). Several studies did not find an effect of ethnicity on FPD (Miller, 1986; Pedrotti et al., 2019; Santagiuliana et al., 2019), while a recent study found higher FPD in Chinese consumers compared to Danish consumers (Cattaneo, Liu, Bech, Pagliarini, & Bredie, 2020). Lingual tactile thresholds did not differ between Belgian and Japanese consumers (Komiyama, Kawara, & De Laat, 2007) and also not between Dutch and Chinese consumers (Santagiuliana et al., 2019) suggesting that ethnicity and/or country of living do not influence lingual tactile thresholds. The distribution of PROP taster status in a population has been suggested to depend on ethnicity or cultural background (Cattaneo et al., 2020; Tepper, 2008). However, this effect has not been confirmed by other studies (Genick et al., 2011; Santagiuliana et al., 2019). To summarize, variations in oral physiology can arise from differences ethnicity or cultural background which potentially may affect sensory sensitivity and perception.

The aim of this case study was to quantify texture (thickness, firmness) and taste (sweetness) sensitivity in Dutch and Chinese adults living in the Netherlands. Three sets of stimuli were used to quantify sensitivity of thickness (maltodextrin solutions differing in viscosity), firmness (agar gels differing in fracture stress) and sweetness (sucrose solutions differing in concentration) perception using the 2-AFC ascending staircase method. Thickness, firmness and sweetness sensitivity were chosen to include texture and taste sensations since they are sensed by different entities of the human sensory system (mechano- and taste receptors). Thickness and firmness were chosen specifically as texture attributes since these attributes can be changed in model food stimuli without considerably changing other texture and taste attributes. This ensures that the discrimination between stimuli in the 2-AFC test is based on the sensory attribute of interest. Saliva flow rate, fungiform papillae density (FPD), lingual tactile threshold and PROP taster status were determined and are here referred to as physiological and sensory consumer characteristics. Two groups of consumers were included in this case study, Dutch and Chinese adults, both living in the Netherlands. We hypothesize that cross-cultural differences influence texture and taste sensitivity. Understanding variation in sensory sensitivity between different consumer groups might help to better understand differences in food choice behavior and food preferences between groups.

2. Materials and methods

2.1. Participants

Eighty-five healthy subjects were recruited, including 44 Dutch (Caucasian) adults (29 females, 22.8 ± 2.3 yrs) and 41 Chinese (Asian) adults (30 females, 24.5 ± 2.1 yrs). Dutch adults had Dutch nationality and Caucasian ethnicity, whereas Chinese adults had Chinese nationality and Asian ethnicity. All participants of the study lived in The Netherlands when the study was performed. Chinese adults lived outside China for less than one year. All participants had a BMI between 18.5 and 25 kg/m^2, no swallowing or mastication disorders, no missing teeth (with the exception of third molars or wisdom teeth), no taste or smell disorders (self-reported) and were generally healthy (self-reported). Participants were recruited via a study website, posters on the university campus, social media and a database. Most participants were students at Wageningen University. Interested participants were invited to an information meeting to fill in an inclusion questionnaire. All participants gave written informed consent to participate in the study. Participants received a financial compensation for their participation. The study was approved by the medical ethical committee of Wageningen University (NL51747.081.14).

2.2. Determination of texture and taste sensitivity

Participants were invited to three sessions of approximately 30 min to quantify texture and taste sensitivity. Within one session, only one set of samples and consequently only one attribute was evaluated by the participants. Data was collected on computers using EyeQuestion (version 4.11.57, Logic8, Elst the Netherlands) in sensory booths of Wageningen University. Participants were instructed to not eat, drink coffee or chew chewing gum two hours before the start of the test session.

Texture and taste sensitivity were assessed using the 2-Alternative Forced Choice (2-AFC) ascending staircase method (Lawless & Heymann, 2013). Maltodextrin solutions, agar gels and sucrose solutions differing in concentration were used to assess thickness, firmness and sweetness sensitivity (Table 1). These specific texture and taste attributes were selected since sets of model foods can be designed which differ in the texture and taste attribute of interest while other texture and taste sensations are not considerably changed. Participants received a pair of two samples (one test sample (Table 1: samples 1–8) and one control sample) and were asked to indicate which sample of the pair was perceived as thicker, firmer or sweeter. Participants received the sets of samples in the same order, starting with sucrose solutions, maltodextrin solutions and agar gels. Maltodextrin solutions (thickness) and sucrose

Table 1
Overview of composition, rheological and mechanical properties of all stimuli used for determination of thickness, firmness and sweetness sensitivity using the 2-AFC ascending staircase method.

Stimulus	Thickness Maltodextrin (g/mL)	Maltodextrin (% w/w)	Viscosity (mPas)	Firmness Agar (g/mL)	Agar (% w/w)	Fracture stress (kPa)	Sweetness Sucrose (g/mL)
Control sample	0	0	0.89	$1.07 * 10^{-5}$	1.07	70.0	0
1	0.0001	0.01	1.00	$1.09 * 10^{-5}$	1.09	72.1	0.0025
2	0.042	4.17	1.50	$1.11 * 10^{-5}$	1.11	74.3	0.005
3	0.083	8.34	2.25	$1.12 * 10^{-5}$	1.12	76.5	0.01
4	0.125	12.51	3.38	$1.14 * 10^{-5}$	1.14	78.8	0.02
5	0.167	16.69	5.06	$1.16 * 10^{-5}$	1.16	81.2	0.04
6	0.209	20.86	7.59	$1.18 * 10^{-5}$	1.18	83.6	0.08
7	0.250	25.03	11.39	$1.20 * 10^{-5}$	1.20	86.1	0.16
8	0.292	29.20	17.09	$1.22 * 10^{-5}$	1.22	88.7	0.32

solutions (sweetness) were provided in medicine cups (15 mL). Agar gels (firmness) were provided as cylindrical disks of 5 mm height and 26 mm diameter. The concentration of the test sample in the 2-AFC test was increased stepwise from one pair to the next pair for up to 8 pairs following the 2-AFC ascending staircase method (Table 1). All participants completed the test for all 8 pairs per session. The sensitivity threshold was determined for each participant for thickness, firmness and sweetness as the test sample with the lowest concentration that has been correctly identified as the more intensive stimulus.

Sensitivity thresholds were determined following two procedures. Individual Best Estimated Thresholds (BET) were calculated as the geometric mean of the highest concentration missed and the next higher concentration correctly identified as more intensive (Lawless & Heymann, 2013). Cumulative frequency of correct answers obtained with the 2-AFC ascending staircase method were calculated for all pairs for thickness as a function of viscosity difference between control stimulus (water) and test sample (maltodextrin solution), for firmness as a function of fracture stress difference between control stimulus (agar gel) and test sample (agar gels) and for sweetness as a function of sucrose concentration difference between control stimulus (water) and test sample (sucrose solutions). Cumulative frequency of correct answers of 75% (half way between chance level (50%) and perfect performance (100%)) was determined as estimate of sensitivity threshold by interpolation of the data assuming linearity.

2.2.1. Sample preparation and characterization

Table 1 provides an overview of all stimuli used. Eight maltodextrin solutions differing in concentration were prepared (Table 1). Maltodextrin (Nutricia, Zoetermeer, The Netherlands) was dissolved in demineralized water. Maltodextrin concentrations were chosen so that viscosity increased stepwise between solutions by a factor of 1.5x. Rheological properties of all maltodextrin solutions were determined using a Modular Compact Rheometer 302 (MCR 302, Anton Par, Graz Austria). Flow curves were recorded by measuring viscosity as a function of shear rate. Shear rate was increased from 0.1 s^{-1} to 1000 s^{-1} and then decreased again. Three replicates were measured and the average viscosity obtained. All maltodextrin solutions displayed Newtonian flow behavior. Sucrose (Van Gilse Kristalsuiker, Dinteloord, The Netherlands) was added to all solutions to match sweetness between solutions. Concentration of added sucrose decreased with increasing maltodextrin concentration since maltodextrin provided a slight sweet taste to the solutions (control sample (water, no maltodextrin): 0.033 g/g sucrose, sample 1: 0.033 g/g sucrose, sample 2: 0.031 g/g sucrose, sample 3: 0.028 g/g sucrose, sample 4: 0.026 g/g sucrose, sample 5: 0.023 g/g sucrose, sample 6: 0.021 g/g sucrose, sample 7: 0.018 g/g sucrose, sample 8: 0.016 g/g sucrose). All solutions were perceived as equally sweet but differed in thickness during a pilot test (data not shown). The pilot test determined sweetness and thickness perception of multiple solutions by $n = 10$ untrained panelists. Panelist rated sweetness and thickness intensity of all stimuli on a 100 mm line scale using EyeQuestion (version 4.11.57, Logic8, Elst The Netherlands). Stimuli that were perceived as equally sweet were selected for the study (Table 1).

Eight agar gels were prepared (Table 1) by hydrating different amounts of agar (Ferwo agar 700, Caldic Ingredients B.V., Oudewater, The Netherlands) and vanilla aroma (Dr. Oetker, Amersfoort, The Netherlands) in demineralized water while stirring for 30 min. Vanilla aroma (0.3 mg/g agar solution) was added to increase palatability. After hydration, agar solutions were heated in a water bath at 95 °C for 45 min while stirring. Warm agar solutions were poured into cylindrical plastic tubes (Omnifix 65 mL syringes, B. Braun, Oss, The Netherlands), which were lightly coated with sunflower oil. Gels were kept in the fridge at 4 °C for at least 12 h to let the agar gels set. After gelation, gels were removed from the tubes and cut into cylindrical disks of 5 mm height and 26 mm diameter. Gels were removed from the fridge 2 h before the start of the test sessions. A previous study suggested that a difference in fracture stress of approximately 10 kPa can be perceived as a difference in firmness of agar gels (Santagiuliana, Piqueras-Fiszman, van der Linden, Stieger, & Scholten, 2018). Agar concentrations were therefore chosen so that fracture stress increased stepwise between agar gels by a factor of 1.2x relative to the control sample (fracture stress of 70 kPa). Mechanical properties of all eight agar gels were determined by uniaxial compression tests using a Texture Analyzer (TA.XT plus, Stable Micro Systems-SMS, Godalming, United Kingdom). The uniaxial compression was performed at room temperature with a speed of 1 mm/s up to a compression strain of 80% using a plate-plate geometry. Paraffin oil was added on top of the gels to minimize friction between gel and plate. Ten replicates were measured and the mean value for fracture stress determined.

Eight sucrose solutions differing in sucrose concentration were prepared by dissolving sucrose (Van Gilse, Dinteloord, The Netherlands) in demineralized water. Sucrose concentrations were chosen so that concentration increased stepwise between sucrose solutions by a factor of 2x Demineralized water was used as control sample. Samples were cooled and served at room temperature.

2.3. Physiological and sensory consumer characteristics

Five parameters describing physiological and sensory consumer characteristics (stimulated and unstimulated saliva flow rate, fungiform papillae density (FPD), lingual tactile threshold, PROP taster status) were quantified during one session of 60 min. The measurements were performed in the same order for all participants (starting with saliva flow rate followed by FPD, lingual tactile threshold and PROP taster status) by a trained researcher on one subject per session.

2.3.1. Stimulated and unstimulated saliva flow rate

Stimulated and unstimulated saliva flow rate of all participants was determined. Five minutes before the measurements participants were not allowed to drink any water and a short break was included between the two measurements. Participants were asked to spit out saliva every 30 s for 5 min into a pre-weighed plastic tube. Every time point when the participant needed to spit out saliva was indicated by the researcher.

The cup was weighed before and after the test session and the unstimulated saliva flow rate (mL/min) obtained. A density of 1 g/mL was assumed for saliva to calculate saliva flow rate. A second saliva collection was done to determine stimulated saliva flow rate. Participants were again asked to spit out saliva every 30 s for 5 min while chewing on a piece of parafilm (5 × 5 cm). Chewing on the parafilm mimics mastication behavior and provides mechanical saliva stimulation. Stimulated saliva flow rate (mL/min) was determined by weighing the cup before and after the measurement.

2.3.2. *Fungiform papillae density (FPD)*

Fungiform papillae density was determined following the Denver Papillae Protocol (Nuessle, Garneau, Sloan, & Santorico, 2015). In brief, participants rinsed their mouth with water and the anterior part of the tongue was stained with blue food coloring (Dr. Oetker, The Netherlands). Pictures on the left and right side of the tongue were taken with a camera (Canon IXUS-500HS). The number of papillae was counted within a circular area of 10 mm diameter on the left and right side of the tongue, approximately 5 mm from the tip of the tongue and 5 mm from the midline. FPD did not differ significantly on the left and right side of the tongue. Therefore, the average FPD was used for data analysis.

2.3.3. *Lingual tactile threshold*

Lingual tactile threshold was determined with a set of Von Frey monofilaments (Baseline, Tactile, Fabrication Enterprises, USA). Von Frey monofilaments consist of nylon threads and are often used to measure tactile sensitivity on hand, feet or facial surfaces (Aktar et al., 2015b; Breen, Etter, Ziegler, & Hayes, 2019; Etter, Miller, & Ballard, 2017; Levin, Pearsall, & Ruderman, 1978). Von Frey filaments differ in the force needed to bend the filament on the tongue, resulting in a specific point pressure that is applied on the tongue. Participants were blind-folded. Then a filament was pressed against the tip of the tongue of the participant or no filament was pressed against the tip of the tongue. Presentation order within pairs was randomized over subjects. Participants were asked to indicate during which trial they perceived the presence of pressure. Two small circles were marked on the left and right side of the tongue with blue food coloring (Dr. Oetker, The Netherlands) to indicate the locations for contact with the Von Frey filament. The location was approximately 5–10 mm from the tip and the midline of the tongue. An descending staircase method (2-AFC) was used with 3 correct identifications resulting in a filament with lower pressure and one incorrect indication of a filament with higher pressure. Participants started the first selection with the filament with the highest force. The oral tactile point pressure threshold was determined by the minimal force of correctly indicated pressure for three filaments in a row. Eight filaments were used with target forces of 0.08, 0.20, 0.39, 0.68, 1.57 and 3.92 mN. A previous study determined the stress applied on the tongue by these Von Frey filaments by determining the mean force of each filament on a lab balance and quantifying the contact area of the filaments (Santagiuliana et al., 2019). The stress applied by the filaments corresponds to 16.08, 21.48, 36.77, 49.62, 86.79 and 133.08 mN mm^{-2}. Lingual tactile threshold did not differ significantly on the left and right side of the tongue. Therefore, the average threshold was used for data analysis.

2.3.4. *PROP taster status*

PROP taster status was determined using 6-n-propylthiouracil (PROP) tasting strips (Bartovation, USA). One strip was placed on the top of the anterior tongue of the participant for 10 s by the researcher. Participants first classified perception of bitterness as no bitter taste (non-tasters), regular bitter taste (medium-tasters) or revolting bitter taste (supertasters). Secondly, participants rated the bitterness intensity on a general Labelled Magnitude Scale (gLMS). Participants with a PROP rating of $\geq$51 ('very strong') were classified as supertasters, with rating $\leq$15.5 ('moderate') as non-tasters and medium-tasters scored in between (Tepper, Christensen, & Cao, 2001). The two measurements of the PROP taster grouping were highly correlated (Pearson Chi-Square $p < .001$, Phi coefficient = 0.863). For the sake of clarity, the PROP taster status obtained by gLMS (continuous parameter) was used for the comparison of consumer groups.

2.4. *Statistical data analysis*

Data was analyzed using SPSS (IBM SPSS statistics, version 25). Normality of the variables was checked and non-normal distributed data was log-transformed. All sensitivity parameters (thickness, firmness and sweetness) and physiological and sensory consumer characteristics (stimulated and unstimulated saliva flow rate, FPD, lingual tactile threshold, PROP taster status) were log-transformed. Data is presented as mean value and standard deviation (SD). Univariate ANOVA's were conducted separately for thickness, firmness and sweetness sensitivity with cultural background (Chinese, Dutch) as fixed factor. Univariate ANOVA's were performed for average FPD, average lingual tactile threshold and PROP taster status by gLMS with cultural background (Chinese, Dutch) as fixed factor. A multivariate ANOVA was performed for unstimulated and stimulated saliva flow rate with cultural background (Chinese, Dutch) as fixed factor. Gender was included in all statistical analysis as covariate since both groups (Chinese, Dutch) were not balanced for gender.

A multivariate linear regression was conducted to study the link between thickness, firmness and sweetness sensitivity and the parameters describing physiological and sensory consumer characteristics. All parameters were standardized to allow for comparison of standardized beta-coefficients. All sensitivity parameters (thickness, firmness and sweetness) were included as dependent variables and 5 physiological and sensory consumer characteristics (unstimulated saliva flow, stimulated saliva flow, FPD, lingual tactile threshold and PROP taster status measured by gLMS) were included as covariates. Multicollinearity of variables was checked by visual inspection of the data using bi-plots, highly correlated variables ($r > 0.7$) and high variance inflation factor ($\text{VIF} > 5$). Based on these criteria no variables showed multicollinearity and therefore no variables were removed from analysis. Pearson correlations of individual thickness, firmness and sweetness sensitivity scores and the five physiological and sensory consumer characteristics were conducted to explore inter-relationships.

3. Results

3.1. *Effect of cross-cultural differences on texture and taste sensitivity*

Best Estimate Threshold (BET) values for thickness, firmness and sweetness sensitivity are shown in Table 2 and cumulative frequency of correct answers obtained with the 2-AFC ascending staircase method for thickness, firmness and sweetness in Fig. 1A–C.

Cultural background did not significantly influence BET for thickness ($p = .956$), firmness ($p = .271$) and sweetness sensitivity ($p = .994$). The BET values for thickness was 2.60 ± 3.24 mPas for Dutch and 2.19 ± 3.20 mPas for Chinese. The estimated thickness threshold that corresponds to 75% correct answers was 3.12 mPas for Dutch and 2.52 mPas

Table 2
Effect of cross-cultural background on Best Estimate Thresholds (BET) for thickness, firmness and sweetness. Mean values are shown with standard deviation.

	Dutch adults (n = 44)	Chinese adults (n = 41)
Thickness sensitivity (mPas)	2.60 ± 3.24	2.19 ± 3.20
Firmness sensitivity (kPa)	10.47 ± 5.09	10.34 ± 4.57
Sweetness detection threshold (g/mL)	0.012 ± 0.038	0.017 ± 0.050

* Effect is significant at $p < 0.05$.

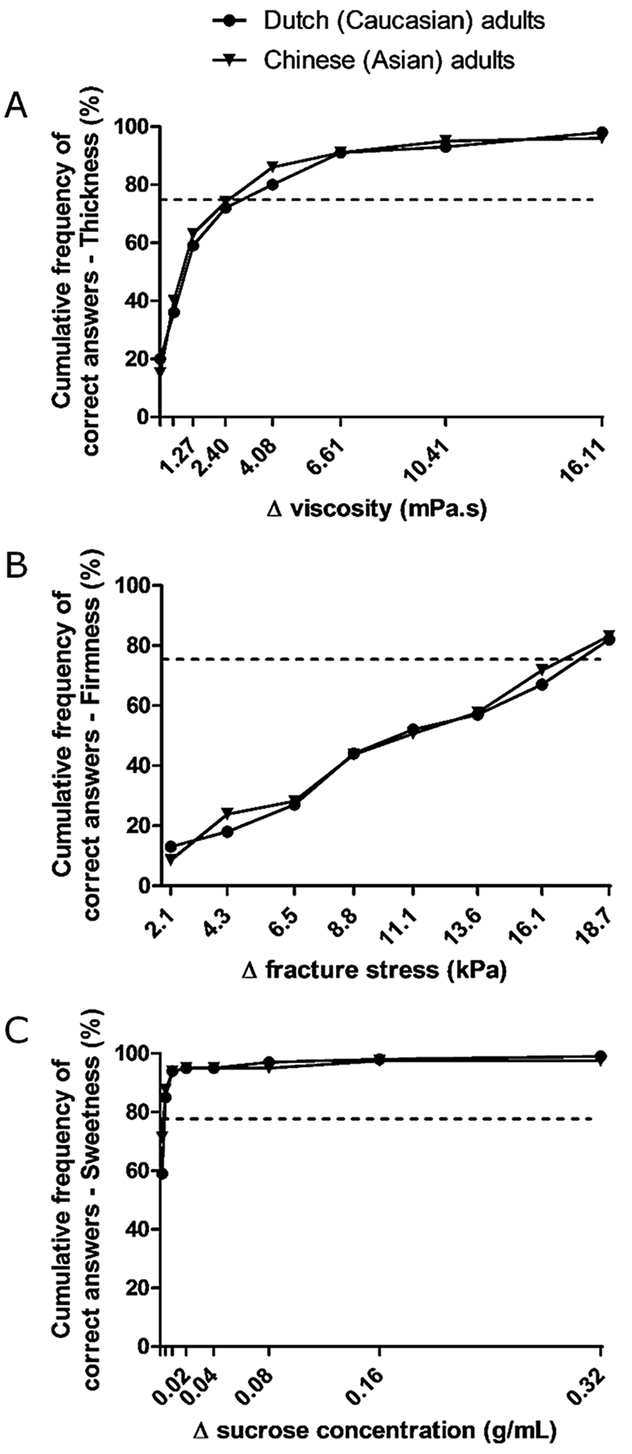

Fig. 1. Cumulative frequency of correct answers obtained with the 2-AFC ascending staircase method for (A) thickness as a function of viscosity difference between control stimulus (water) and maltodextrin solutions, (B) firmness as a function of fracture stress difference between control stimulus (agar gel) and agar gels and (C) sweetness as a function of sucrose concentration difference between control stimulus (water) and sucrose solutions. Dutch adults (n = 44) are represented as circles and Chinese adults (n = 41) as triangles. Dotted lines indicate a cumulative frequency of correct answers of 75%.

for Chinese (Fig. 1A). The BET values for firmness were 10.5 ± 5.1 kPa for Dutch and 10.3 ± 4.6 kPa for Chinese. The estimated firmness threshold that corresponds to 75% correct answers was 17.5 kPa for Dutch and 16.8 kPa for Chinese (Fig. 1B). The BET values for sweetness was 0.013 ± 0.038 g/mL for Dutch and 0.017 ± 0.050 g/mL for Chinese. The estimated sweetness threshold that corresponds to 75% correct answers was 0.0040 g/mL for Dutch and 0.0031 g/mL for Chinese (Fig. 1C).

Pearson's correlations revealed that thickness, firmness and sweetness thresholds were not significantly correlated ($p > .05$).

3.2. *Effect of cross-cultural differences on physiological and sensory consumer characteristics*

Stimulated and unstimulated saliva flow rate, fungiform papillae density (FPD), lingual tactile threshold and PROP taster status of all participants are shown in Table 3.

3.2.1. *Saliva flow rate*

Saliva flow rate, both unstimulated and stimulated, was not significantly affected by cultural background (unstimulated: $p = .309$; stimulated: $p = .687$). Dutch had an unstimulated saliva flow rate of 0.54 ± 0.38 g/mL compared to 0.50 ± 0.29 g/mL for Chinese. Stimulated saliva flow was 1.35 ± 0.61 g/mL for Dutch and 1.33 ± 0.67 g/mL for Chinese.

3.2.2. *Fungiform papillae density (FPD)*

Fungiform papillae density (FPD) was significantly ($p = .032$) different for Dutch (16.9 ± 3.7 count/cm^2) and Chinese (15.4 ± 4.1 count/cm$^{2)}$, indicating a slightly higher number of fungiform papillae density of Dutch compared to Chinese.

3.2.3. *Lingual tactile threshold*

Lingual tactile threshold was not affected by cultural background ($p = .153$). Dutch had a lingual tactile threshold of 2.26 ± 0.79 g mm^{-2} compared to 2.05 ± 0.78 g mm^{-2} for Chinese.

3.2.4. *PROP taster status*

PROP taster status was not significantly affected by cultural background ($p = .527$). For Dutch 27.3% were non-tasters, 52.3% medium-tasters and 20.5% supertasters of PROP. Chinese had a similar distribution with 24.4% non-tasters, 43.9% medium-tasters and 31.7% supertasters of PROP.

3.3. *Linking texture and taste sensitivity to physiological and sensory consumer characteristics*

A multivariate linear regression model was performed to assess relationships between thickness, firmness and sweetness sensitivity and saliva flow rate (stimulated and unstimulated), FPD, lingual tactile threshold and PROP taster status. Fourteen out of 15 relationships between texture and taste sensitivity and physiological and sensory consumer characteristics were not significantly correlated ($p > .05$). The only significant and weakly positive correlation ($B = 0.286$, $p = .036$)

Table 3
Effect of cross-cultural background on physiological and sensory consumer characteristics (saliva flow rate, PROP taster status, fungiform papillae density, lingual tactile threshold). Mean values are shown with standard deviation for different consumer groups.

	Dutch adults (n = 44)	Chinese adults (n = 41)
Saliva flow rate		
Unstimulated (g/mL)	0.54 ± 0.38	0.50 ± 0.29
Stimulated (g/mL)	1.35 ± 0.61	1.33 ± 0.67
PROP taster status		
Non-taster (%)	27.3	24.4
Medium-taster (%)	52.3	43.9
Super-taster (%)	20.5	31.7
Fungiform papillae density (count/cm^2)	16.9 ± 3.7 *	15.4 ± 4.1 *
Lingual tactile threshold (g mm^{-2})	2.26 ± 0.79	2.05 ± 0.78

* Effect is significant at $p < 0.05$

found was between firmness sensitivity and FPD indicating that participants with a higher FPD were associated with a slightly higher firmness threshold, so with a slightly lower firmness sensitivity. The MANOVA indicated that PROP taster status, measured as categorical parameter, did not have a significant effect on thickness ($p = .105$), firmness ($p = .250$) and sweetness ($p = .089$) sensitivity.

4. Discussion

The aim of this case study was to quantify texture (thickness, firmness) and taste (sweetness) sensitivity in Dutch and Chinese adults living in the Netherlands. In this case study no significant differences in thickness, firmness and sweetness sensitivity were observed between Dutch and Chinese adults living in the Netherlands for less than 1 year. No significant differences in saliva flow rate, lingual tactile threshold and PROP status were observed between Dutch and Chinese living in the Netherlands for less than 1 year. Fourteen out of 15 relationships between texture and taste sensitivity (thickness, firmness and sweetness) and physiological and sensory consumer characteristics (stimulated and unstimulated saliva flow rate, FPD, lingual tactile threshold, PROP taster status) were not significantly related. The only significant and weakly positive correlation was between firmness sensitivity and FPD, indicating that participants with a higher FPD were associated with a slightly higher firmness threshold.

Texture and taste sensitivity were not different between Dutch and Chinese living in the Netherlands. These results are in line with a previous study investigating particle size detection thresholds in various foods giving rise to grittiness perception. Particle size detection threshold did not differ between Dutch and Chinese (Santagiuliana et al., 2019). Cattaneo and colleagues reported that lingual tactile acuity does not differ between Asian (Chinese) and Caucasian (Danish) populations (Cattaneo et al., 2020). This suggests that texture sensitivity in general (thickness, firmness, grittiness) might be stable across populations originating from different geographical locations, having different cultural backgrounds and belonging to different ethnicities. Only little evidence can be found demonstrating an effect of ethnicity on sensory perception (Bertino, Beauchamp, & Jen, 1983). The majority of studies found remarkable similarities in sensory properties of foods assessed by consumers differing in cultural background (Blancher et al., 2008; Lundgren et al., 1986; Prescott & Bell, 1995; Teo et al., 2018). Differences in dietary habits of consumers belonging to different cultural groups have been suggested to affect taste sensitivity (Rozin et al., 1981). The relationships between dietary habits and taste sensitivity have not been investigated in the current study, so future studies are needed to explore these relationships. The two adult groups of the current study differed in ethnicity (Asian, Caucasian), but were both living in the Netherlands. The Chinese adults have been living in the Netherlands for less than one year. Living in the Netherlands might have led to changes in dietary habits and sensory perception of the Chinese adults. We emphasize that the results of this case study cannot be generalized towards Caucasian and Asian ethnicities.

The BET value for sweetness in our study was on average 0.015 g/mL. Previously, lower sweetness thresholds of 0.0036 g/mL have been reported for Caucasian Americans (Hyde & Feller, 1981), Chinese adults (0.004 g/mL) (Shu-Fen, Tey, Henry, & Forde, 2018) and Balinese adults (0.011 g/mL) (Fibrianto & Wicaksana, 2016). The difference in sweetness threshold between the current and previous studies could be due to the selected sucrose concentrations of the current study. The majority of participants (67.2%) was able to correctly select the sweetest sample already in the 2-AFC pair that compared the lowest sucrose concentration (0.0025 g/mL) with water. Including lower sucrose concentrations than 0.0025 g/mL in the current study would have allowed to determine the sweetness BET value more accurately. The sweetness threshold found in this study might therefore be an overestimation. We acknowledge this limitation and emphasize that the sweetness BET value should be interpreted with caution.

The current study did not find an effect of cultural background on any of the physiological and sensory consumer characteristics. Saliva flow did not differ between Dutch and Chinese, which is in line with previous studies (Ketel et al., 2020; Santagiuliana et al., 2019). The current study did find an effect of cultural background on FPD, however the difference between Chinese and Dutch adults was small. Previous studies were not able to find difference in FPD between consumers of different cultural backgrounds or ethnicities (Miller, 1986; Pedrotti et al., 2019; Santagiuliana et al., 2019). Lingual tactile threshold was not affected by cultural background in the current study. Several studies investigated the effect of cultural background on lingual tactile threshold and found no difference between different ethnicities (Cattaneo et al., 2020; Essick, Chopra, Guest, & McGlone, 2003; Komiyama et al., 2007; Santagiuliana et al., 2019). The average lingual tactile threshold of the current study was rather low (mean: 2.16 g mm^{-2}). Most participants (69.4%) correctly sensed already a tactile stimulation of the weakest Von Frey filament used (1.64 g mm^{-2}). This suggests that a floor effect occurred and that the lingual tactile threshold of these participants of our study might be lower. Consequently, the current study might overestimate the lingual tactile threshold and an accurate determination of the lingual tactile thresholds was not possible with these Von Frey filaments. Similar limitations of these Von Frey filaments have been reported previously (Santagiuliana et al., 2019). Since the Von Frey filaments are originally developed to test tactile finger sensitivity, the filaments seem to be not sufficiently sensitive to determine lingual tactile thresholds accurately. More sensitive methods need to be developed to do so. The current study did not find an effect of cultural background on PROP taster status. Previous studies proposed that ethnicity could influence PROP taster status (Baranowski et al., 2010; Tepper, 2008). However, no studies so far have been able to confirm this relationship.

The current study investigated the relationships between sensory sensitivity and physiological and sensory consumer characteristics. Only one significant and weak relationship was found between firmness sensitivity and FPD out of 15 possible relationships. Small within-group variation could have contributed to the lack of significant relationships. However, we consider the within-group variation of the current to be not small. PROP taster status, saliva flow rate (unstimulated and stimulated) and lingual tactile threshold did not significantly relate with firmness, thickness and sweetness sensitivity. This is in line with a recent study investigating the relationships between grittiness sensitivity and the same physiological and sensory consumer characteristics in similar consumer groups (Santagiuliana et al., 2019). Particle size detection was only related to salivary flow in semi-solid foods and no other significant relationships were found between grittiness sensitivity and physiological and sensory consumer characteristics. Higher sucrose detection threshold in PROP non-tasters compared to tasters have been reported in South-Korean adults (Chang et al., 2006; Hong et al., 2005) and Irish children (Feeney, O'Brien, Scannell, Markey, & Gibney, 2014). The current study did not find a relationship between sucrose detection threshold and PROP taster status measured by grouping and gLMS. It is not clear why the relationship was not found in the current study. Several studies found links between FPD and sweetness, creaminess and fattiness sensitivity (Hayes, Bartoshuk, Kidd, & Duffy, 2008; Hayes & Duffy, 2007; Nachtsheim & Schlich, 2013), while other studies did not find links between FPD and bitterness and roughness sensitivity (Bakke & Vickers, 2008, 2011). The link between FPD and sensory sensitivity remains unclear in view of these contradicting results between studies. The link between PROP taster status and various sensory sensitivities has been investigated across different sensory properties with several studies finding relationships (de Wijk, Dijksterhuis, Vereijken, Prinz, & Weenen, 2007; Essick et al., 2003; Hayes & Duffy, 2007) while other studies did not find relationships (Bakke & Vickers, 2008; Nachtsheim & Schlich, 2013; Yackinous & Guinard, 2001). Green and colleagues suggested that caution should be taken when predicting sensory sensitivity with PROP sensitivity (Green, Alvarez-Reeves, George, & Akirav, 2005).

We conclude that the link between sensory sensitivity and physiological and sensory consumer characteristics is still unclear and needs to be explored further. Previously, dietary habits have been related to taste sensitivity (Rolls, 1999; Rozin, Mark, & Schiller, 1981; Schiffman, 1993). Since the current study did not find taste (sweetness) and texture (thickness, firmness) sensitivity differences between consumer groups, this suggests that cross-cultural differences in dietary habits between ethnicities or consumer living in different countries and cultures cannot be explained solely by taste and texture sensitivities. Thickness and firmness were chosen specifically as texture attributes since these attributes can be changed in model stimuli without considerably changing other texture and taste properties. Future studies could explore the effect of cross-cultural differences on other texture attributes such as stickiness and chewiness. It has been suggested that Asian and Western diets differ regarding these food texture properties. Hence, an effect of cross-cultural differences on stickiness and chewiness sensitivity might be observed. It should be noted that it remains difficult to develop foods that differ only in one texture attributes, for example chewiness or stickiness, without affecting perception of other texture attributes. Cultural factors might play a considerably larger role than taste and texture sensitivity determining dietary habits of consumers belonging to different ethnicities. It is worth noting that dietary habits of the participants were not determined in this study. Therefore, not only ethnicity or cultural background but other factors such as types of frequently consumed foods may also affect thickness, firmness and sweetness sensitivity. Future large scale studies should determine the effect of dietary food intake on texture and taste sensitivities. It should also be noted that the Chinese adults were living in the Netherlands, for a maximum of 1 year. This group is not representative for the general population of Chinese adults. Future studies could include multinational studies including Chinese adults living in China and Dutch adults living in the Netherlands. Future studies should include large-scale comparisons of other ethnicities, to fully comprehend sensory sensitivity and consumer's characteristics.

5. Conclusions

The aim of this case study was to quantify texture and taste sensitivity in Dutch and Chinese adults living in the Netherlands. We conclude that texture (thickness, firmness) and taste (sweetness) sensitivity do not differ between Dutch and Chinese adults living in the Netherlands. Saliva flow rate, fungiform papillae density, lingual tactile threshold and PROP taster status do not explain inter-individual variation in these sensory sensitivities between consumers.

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CRediT authorship contribution statement

Eva C. Ketel: Investigation, Methodology, Project administration, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **René A. de Wijk:** Funding acquisition, Conceptualization, Methodology, Writing - review & editing. **Cees de Graaf:** Funding acquisition, Conceptualization, Methodology. **Markus Stieger:** Funding acquisition, Conceptualization, Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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