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► **To cite this version:**

Martine Hennequin, Nada El Osta, Marie-Laure Munoz-Sanchez, Mathilde Vandenberghe Descamps, Valentina A Andreeva, et al.. Age related impairments in ingestion from a large population based-sample. *Appetite*, 2024, 196, pp.107287. 10.1016/j.appet.2024.107287 . hal-04497878

**HAL Id: hal-04497878**

**<https://uca.hal.science/hal-04497878>**

Submitted on 11 Mar 2024

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## Age related impairments in ingestion from a large population based-sample

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### ARTICLE INFO

Handling Editor: Prof. M.M. Hetherington

#### Keywords:

Aged nutrition physiology  
Disability evaluation  
International classification of functioning  
Oral health related quality of life  
BMI  
Xerostomia

### ABSTRACT

**Objectives:** Epidemiological data regarding the evolution of problems related to mastication and swallowing with age are lacking. This study aims to (i) describe changes in oral function with age, using data from a large French population, (ii) validate online, self-report uses of an ICF questionnaire in older persons, and (iii) assess whether impairment is related to avoidance of certain foods, xerostomia, body mass index (BMI) and oral health related quality of life (OHRQoL).

**Methods:** Volunteers aged  $\geq 18$  years with internet access completed a series of questionnaires on sociodemographic, anthropometric and oral health characteristics (oral function, Xerostomia Index (XI), OHRQoL, reasons for avoidance of certain food). Oral function was assessed using items derived from the International Classification of Functioning (ICF). Five ICF items related to ingestion function and six items related to activities and participation were used. A validation study was undertaken to identify those with poor chewing ability and low salivary flow amongst older participants reporting impairment.

**Findings:** 39 597 individuals were included. The prevalence of individuals with impairment for ICF items related to ingestion function and oral activity (eating, drinking and speaking), and the percentage of participants with poor OHRQoL increased significantly with age ( $p < 0.001$ ). Each ICF item was significantly associated with OHRQoL ( $p < 0.001$ ), XI ( $p < 0.001$ ), BMI ( $p < 0.001$ ) and avoidance of certain food due to chewing or swallowing difficulties.

**Conclusion:** Overall, 21.5% and 13.5% of the study population had chewing and/or biting impairments respectively, which might affect food selection and consumption. These findings raise individual and population-based issues. Further studies are needed to assess whether impairment in oral function might increase frailty in older individuals, and also to compare data with those from other countries.

### 1. Introduction

Poor oral health affects mastication (Bourdiol et al., 2020; Peyron &

Woda, 2016), has an impact on food choice in the daily diet (Foster et al., 2006) and consequently, may affect nutritional status (El Osta et al., 2019a, 2022). Associations between dental status, chewing

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<https://doi.org/10.1016/j.appet.2024.107287>

Received 23 November 2023; Received in revised form 23 February 2024; Accepted 26 February 2024

Available online 6 March 2024

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**Table 1**

ICF oral health-related items selected to characterize oral function. Participants were asked if they had difficulties with each item.

|   |                                   |   |
|---|-----------------------------------|---|
| Ingestion function  |                                   |   |
| b5101   | Biting                            | Functions of cutting into piercing or tearing off food with the front teeth.  |
| b5102   | Chewing                           | Functions of crushing, grinding and masticating food with the back teeth (e.g. molars).   |
| b5103   | Manipulation of food in the mouth | Functions of moving food around the mouth with the teeth and tongue.  |
| b5104   | Salivation                        | Function of the production of saliva within the mouth.  |
| b5105   | Swallowing                        | Functions of clearing the food and drink through the oral cavity, pharynx and esophagus into the stomach at an appropriate rate and speed   |
| Activities and participation  |                                   |   |
| d520  | Caring for teeth                  | Looking after dental hygiene, such as by brushing teeth, flossing, and taking care of a dental prosthesis or orthosis.  |
| d550  | Eating                            | Carrying out the coordinated tasks and actions of eating food that has been served, bringing it to the mouth and consuming it in culturally acceptable ways, cutting or breaking food into pieces, opening bottles and cans, using eating implements, having meals, feasting or dining                                    |
| d560  | Drinking                          | Taking hold of a drink, bringing it to the mouth and consuming the drink in culturally acceptable ways; mixing, stirring and pouring liquids for drinking, opening bottles and cans, drinking through a straw or drinking running water, such as from a tap or a spring; feeding from the breast                          |
| d630  | Preparing meals                   | Planning, organizing, cooking and serving simple and complex meals for oneself and others, such as by making a menu, selecting edible food and drink, getting together ingredients for preparing meals, cooking with heat and preparing cold foods and drinks, and serving the food                                       |
| d570  | Looking after one's health        | Ensuring physical comfort, health and physical and mental well-being, such as by maintaining a balance diet and an appropriate level of physical activity, keeping warm or cool, avoiding harm to health, following safe sex practices, including using condoms, getting immunizations and regular physical examinations. |
| Others  |                                   |   |
| d330  | Speaking                          | Producing words, phrases and longer passages in spoken messages with literal and implied meaning, such as expressing a fact or telling a story in oral language   |
| Impairment  |                                   | Scoring   |
| No impairment   |                                   | 0   |
| Mild impairment means a problem that is present less than 25% of the time, with an intensity which is tolerable and which happens rarely over the last 30 days (less than one time in four)   |                                   | 1   |
| Moderate impairment means that a problem is present less than 50% of the time, with an intensity which interferes in day-to-day life and which happens occasionally over the last 30 days (less than one time in two)                     |                                   | 2   |
| Severe impairment means that a problem is present more than 50% of the time, with an intensity which partially disrupts day to day life and which happens frequently over the last 30 days (more than one time in two, but not each time) |                                   | 3   |
| Complete impairment means that a problem is present over 95% of the time, with an intensity that totally disrupts day to day life and happens every day over the last 30 days (at least one time in ten)                                  |                                   | 4   |

capacity and food choice have been reported in numerous small-sample studies (Allen, 2005; Lin et al., 2010), and it has been suggested that these associations increase with age. Epidemiological dental studies involving large samples have focused on the increasing prevalence of caries, edentulism and periodontal disease with age (Kim et al., 2012), while issues related to ingestion functions have been largely ignored (Iwata & Sessle, 2019).

Research concepts on food ingestion differ widely between the food and health sciences. In food sciences, the term "Food Oral Processing" includes all actions involved in transforming food into a food bolus that can be swallowed safely (Chen, 2009). In the medical sciences, the term chewing is often used in a trivial sense, grouping together in a single word all the functions involved in ingestion, ignoring the specific functions of ingestion such as biting, chewing, sucking, manipulating food with the tongue and cheeks, and swallowing (Chen, 2009). Depending on the texture of the food, each of these oral functions has a different impact on food oral processing. For example, manipulating a banana with the tongue and cheeks is enough to obtain a food bolus for swallowing, whereas biting and chewing are required for a piece of meat or a raw apple.

It is not known how problems related to ingestion functions evolve with age, whether they evolve gradually according to a linear law, or appear suddenly with an exponential progression. This information is needed in two scientific fields. Firstly, in the health sciences, the presence of oral function impairments could be assessed for the early identification of individuals at risk of restrictive diet and poor nutritional status. In this instance, the goal is to determine the best solution between dental rehabilitation and adaptation of food texture.

Secondly, in the field of food science, epidemiological data are needed to produce new foods with a wide range of textures (Araiza-Calahorra et al., 2023), that are adapted to the reduced food oral processing capacity of individuals for whom dental rehabilitation is not possible due to medical, cognitive, physical, financial or behavioral

difficulties. In terms of population, it is therefore imperative to describe the distribution of impairment in ingestion functions during ageing, and to examine the resulting food selection problems.

The International Classification of Functioning, Disability and Health (ICF) (Kostanjsek, 2011; Leonardi et al., 2022; World Health Organisation, 2001), provides both a conceptual framework and a practical dictionary for describing health and health-related states. Its multilingual nature facilitates the production of comparable data across different countries. The ICF may be used to describe and to qualify the different aspects of ingestion function, activities and participation (Dougall et al., 2015, 2018; Faulks & Hennequin, 2006). The use of the ICF in oral health may broaden professional approaches to clinical decision-making, research and epidemiology (Dougall et al., 2015). Currently, no studies have used the ICF indicators of ingestion and oral function as a self-report measure.

This study aims to (i) describe changes in oral function with age, using data from a large French population, (ii) validate online, self-report uses of an ICF questionnaire in older persons, and (iii) assess whether impairment is related to avoidance of certain foods, xerostomia, body mass index (BMI) and oral health related quality of life (OHRQoL).

## 2. Methods

This observational analytical study reports data from an epidemiological survey collected through the NutriNet-Santé e-cohort and an ancillary study conducted to validate the ICF data recorded online, supported by the French ALIMASSENS project (ANR-14-CE20-0003).

### 2.1. Study design

The epidemiological component of the study is based on data from an ongoing population-based e-cohort launched in France in 2009 called

**Table 2**  
Xerostomia Inventory index.

|       |   |
|-------|---|
| XI 1  | I sip liquids to aid in swallowing food             |
| XI 2  | My mouth feels dry when eating a meal               |
| XI 3  | My lips feel dry                                    |
| XI 4  | I have difficulties swallowing certain foods        |
| XI 5  | My mouth feels dry                                  |
| XI 6  | I get up at night to drink                          |
| XI 7  | I have difficulty eating dry foods                  |
| XI 8  | My eyes feel dry                                    |
| XI 9  | I suck sweets or cough lollies to relieve dry mouth |
| XI 10 | The inside of my nose feels dry                     |
| XI 11 | The skin of my face feels dry                       |

**Table 3**  
Distribution of participants according to household income, educational level, BMI, impairment of oral function and activity, perceived oral health related quality of life (GOHAI) and Xerostomia Inventory (N = 39 597).

|   |                |
|---|----------------|
| Monthly household income n (%)                        |                |
| < 1200 Euros  | 3780 (9.5%)    |
| 1200–1799 Euros                                       | 7776 (19.6%)   |
| 1800–2699 Euros                                       | 10 001 (25.3%) |
| ≥2700 Euros   | 12 471 (31.5%) |
| Missing values  | 5569 (14.1%)   |
| Educational level n (%)                               |                |
| Up to high school                                     | 6966 (17.6%)   |
| Undergraduate degree                                  | 5399 (13.6%)   |
| Graduate degree                                       | 27 180 (68.6%) |
| Missing values  | 52 (0.1%)      |
| BMI in kg/m <sup>2</sup> mean ± SD; n (%)             |                |
| BMI < 18.5  | 1873 (4.7%)    |
| BMI 18.5–24.99  | 24 356 (61.5%) |
| BMI 25–29.99  | 9505 (24.0%)   |
| BMI 30–34.99  | 2712 (6.8%)    |
| BMI ≥ 35  | 1151 (2.9%)    |
| Impairments for ICF items n (%)                       |                |
| Biting  | 5341 (13.5%)   |
| Chewing   | 8532 (21.5%)   |
| Manipulation of food in the mouth                     | 2054 (5.2%)    |
| Salivation  | 2487 (6.3%)    |
| Swallowing  | 3402 (8.6%)    |
| Caring for teeth                                      | 4468 (11.3%)   |
| Eating  | 1051 (2.7%)    |
| Drinking  | 430 (1.1%)     |
| Looking after one's health                            | 6432 (16.2%)   |
| Preparing meals                                       | 4205 (10.6%)   |
| Speaking  | 2344 (5.9%)    |
| GOHAI n (%)   | 53.70 ± 5.53   |
| Poor OHRQoL <sup>a</sup> , low score ≤ 50             | 9078 (22.9%)   |
| Moderate OHRQoL <sup>a</sup> , moderate score 51 - 56 | 15 463 (39.1%) |
| Very good OHRQoL <sup>a</sup> , high score 57 - 60    | 15 056 (38.0%) |
| Xerostomia Inventory score mean ± SD                  | 19.09 ± 5.30   |

<sup>a</sup> OHRQoL: Oral Health Related Quality of Life.

NutriNet-Santé. The design, recruitment strategies, and methodology have been described previously (Herberg et al., 2010; Kesse-Guyot et al., 2013). The NutriNet-Santé study was approved by the ethics committee of the French Institute of Health and Medical Research (No. 0000388FWA00005831) and by the National Commission on Informatics and Liberty (No. 908450 and No. 909216). Enrollment and participation take place exclusively online via a dedicated and secure website (L'étude Nutrinet-Santé, n.d.). All adults can volunteer for this longitudinal study and the only exclusion criteria relate to adulthood; access to the internet; possession of a personal email address; provision of informed consent and an electronic signature. Participants provide base-line data including sociodemographic and lifestyle characteristics, health status, and anthropometric data. They are regularly solicited to complete different questionnaires relating to their nutrition, physical activity and health. Between March and September 2016 questions relating to oral function were included in the NutriNet-Santé project and these provided the data for the current study.

## 2.2. Study criteria

### 2.2.1. Oral function

Questions relating to oral function were derived from the Classification of Functioning, Disability and Health (ICF) (Dougall et al., 2015; World Health Organisation, 2001). Of the 119 items of the ICF identified as relevant to oral health or oral function in a previous study (Dougall et al., 2015), eleven were selected for insertion in the NutriNet Santé project: five items related to ingestion function (biting, chewing, manipulating food in the mouth, salivating, and swallowing) and six items related to activities and participation (caring for teeth, eating, drinking, preparing meals, speaking, and looking after one's health). The description of these items and their scoring is presented in Table 1.

### 2.2.2. Oral health related quality of life

The General Oral Health Assessment Index (GOHAI) is a tool to evaluate oral health-related quality of life (OHRQoL) and a validated French translation is available (Atchison & Dolan, 1990; Denis et al., 2017; Tubert-Jeannin et al., 2003). Responses are scored on a Likert scale ranging from 1 to 5. An overall ADD-GOHAI score was obtained by summing the scores for the 12 items, ranging from 12 to 60. A score of 57–60 indicates good OHRQoL, while a score between 51 and 56 is categorized as moderate. A score of 50 or less is indicative of poor OHRQoL (Atchison & Dolan, 1990). The GOHAI also comprises three dimensions: a functional dimension (4 items related to eating, speaking and swallowing; maximum score = 20); a psychosocial dimension (5 items related to concerns about self-consciousness, self-image, and avoiding social interactions; maximum score = 25); and a pain or discomfort dimension (3 items related to drugs, gingival sensitivity and discomfort when chewing certain foods; maximum score = 15).

### 2.2.3. Xerostomia

Participants were asked to complete the French version of the Xerostomia Inventory (XI) which includes 11 items (Pierrard et al., 2022; Thomson et al., 1999) (Table 2). Participants were asked to indicate which of the 5 response options best described their symptoms during the previous month. The response options were: never (score 1); hardly ever (2); occasionally (3); fairly often (4); or very often (5). The response scores for the 11 items are summed resulting in a total XI score ranging from 11 (no dry mouth) to 55 (extreme dry mouth).

### 2.2.4. Avoidance of certain foods

Limitation in food intake was assessed using a questionnaire asking whether the main reason for avoidance of the following food categories was difficulty chewing or swallowing (yes/no): meat (red, white, poultry), deli meat (such as dry sausage and cured ham), raw vegetables, and crusty bread (Andreeva et al., 2018).

### 2.2.5. Covariates

Covariates included self-reported gender, age, educational level, and monthly household income. Participants gave their height and weight, which were used to calculate body mass index (BMI = weight [kg]/height [m]<sup>2</sup>). They also rated their overall oral health on a 6-point scale from excellent to very poor (Dougall et al., 2018).

## 2.3. Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics version 28.0. The alpha error was set at 5.0%. Chi-square tests and Fisher Exact tests were applied for categorical variables and analysis of variance (ANOVA) and Student t tests for quantitative variables.

The influence of age in older individuals (≥60 years) was assessed in relation to ICF ingestion function, OHRQoL and xerostomia. Each ICF ingestion function (categorized into presence or absence of impairment) and the dichotomized GOHAI score (≤50 versus >50) were the dependent dichotomized variables. The XI score, each domain score of GOHAI

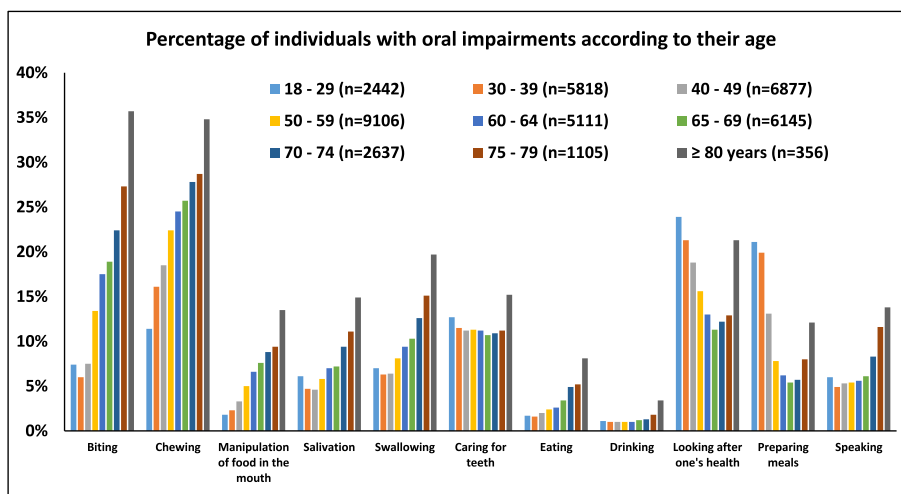


Fig. 1. Prevalence of participants with at least one impairment in each ICF item across various age groups (N = 39 597).

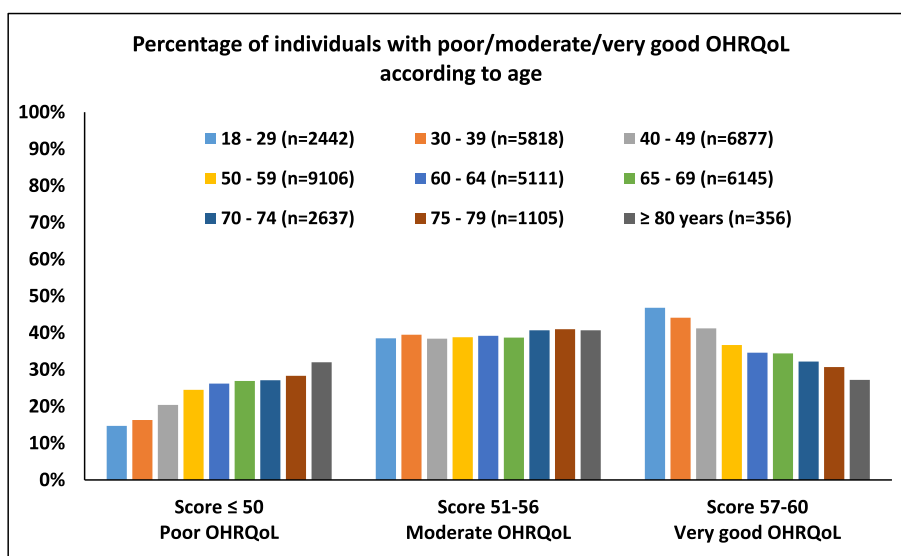


Fig. 2. Variation of Oral Health-related Quality of Life across different age groups (N = 39 597).

were the continuous dependent variables. Age categories of 60–79 years and ≥80 years were the explanatory variables. The controlled variables were BMI and gender. Univariate analyses followed by multivariate analyses were performed to assess the association between (i) ICF ingestion function and age, (ii) GOHAI and age, and (iii) XI and age whilst controlling for BMI and gender.

Univariate analyses were performed using Chi-square tests for categorical variables and Student t tests for continuous variables. Logistic regression was performed for each dichotomized dependent variable (impairment or not for biting; chewing; manipulating food in the mouth; salivating; swallowing; and GOHAI score ≤50 vs. >50). Age (60–79 years and ≥80 years), BMI and gender were included in each logistic regression. Odds ratios (OR) with 95% confidence interval were calculated to quantify the strength of associations between each dependent variable and age.

Similarly, multiple regression analyses were performed for each continuous dependent variable (XI score; GOHAI physical function score; GOHAI pain and discomfort score; GOHAI psychosocial impact score); age (60–79 years and ≥80 years), BMI, and gender were included in multiple regression analyses. The mean difference with 95% confidence interval and correlation coefficient was calculated to quantify the association between each dependent variable and age.

#### 2.4. Validation study of ICF items related to oral function in older people

##### 2.4.1. Design

Validation of the ICF questionnaire was necessary because the online use of the ICF items as a online self-reported questionnaire had not been previously validated in older persons. The validation study was designed to identify poor chewing capacity, poor chewing performance and low salivary flow amongst older participants declaring the presence of impairment based on the eleven ICF items relating to oral function. A panel of 50 volunteers aged over 65 years (22 women, average age 71.7 ± 4.5 years, and 28 men, average age 71.6 ± 5.3 years), living in Dijon, France, was recruited. It was made up of participants in the five-year multidisciplinary ALIMASSENS Collaborative Project launched in France in 2014 ([Toward Offering Healthy Food Products Better Adapted to Elderly People, n.d.](#)), aimed to design innovative food products for older populations living at home (ANR-14-CE20-0003). The recruitment criteria were as follows: participants had to be older than 65 years old, free of acute pathological episodes at the time of the study, and score at least 24 on the Mini-Mental State Examination, indicating normal cognition ([Folstein et al., 1975](#)).

The experimental protocol was approved by the French Ethics Committee for Research (CPP Est I, Dijon, #14.06.03, ANSM #2014-

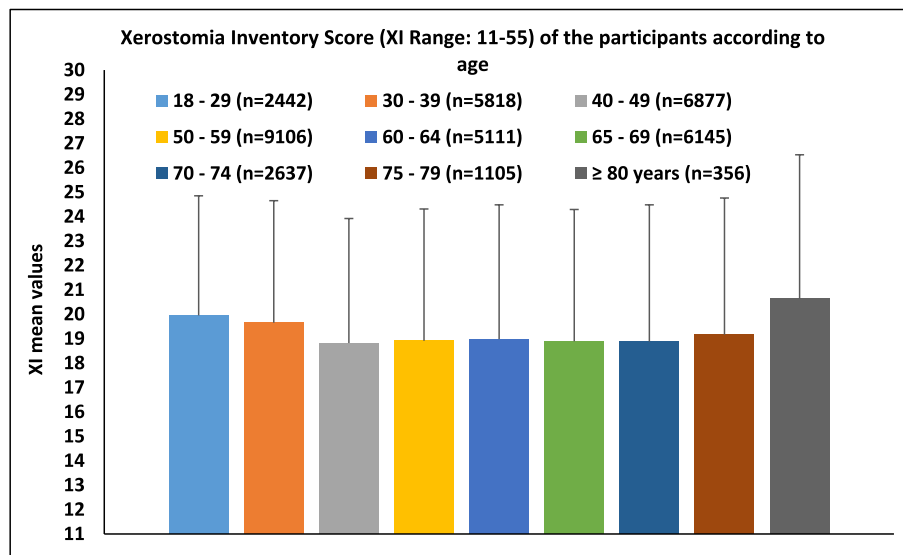


Fig. 3. Variation of mean values in Xerostomia Inventory scale across different age groups (N = 39 597).

**Table 4**  
Distribution of participants according to BMI values and age categories.

| Age in years | BMI kg/m <sup>2</sup> |                             |                       |                    |                       |
|--------------|-----------------------|-----------------------------|-----------------------|--------------------|-----------------------|
|              | <18.5 (Underweight)   | 18.5–24.99 (Healthy weight) | 25–29.99 (Overweight) | 30–34.99 (Obesity) | ≥35 (Extreme obesity) |
| 18–29        | 265 (10.9%)           | 1798 (73.6%)                | 283 (11.6%)           | 63 (2.6%)          | 33 (1.4%)             |
| 30–39        | 436 (7.5%)            | 4079 (70.1%)                | 917 (15.8%)           | 254 (4.4%)         | 132 (2.3%)            |
| 40–49        | 364 (5.3%)            | 4388 (63.8%)                | 1440 (20.9%)          | 452 (6.6%)         | 233 (3.4%)            |
| 50–59        | 389 (4.3%)            | 5589 (61.4%)                | 2191 (24.1%)          | 646 (7.1%)         | 291 (3.2%)            |
| 60–64        | 166 (3.2%)            | 2946 (57.6%)                | 1384 (27.1%)          | 433 (8.5%)         | 182 (3.6%)            |
| 65–69        | 160 (2.6%)            | 3398 (55.3%)                | 1877 (30.5%)          | 525 (8.5%)         | 185 (3.0%)            |
| 70–74        | 71 (2.7%)             | 1373 (52.1%)                | 892 (33.8%)           | 227 (8.6%)         | 74 (2.8%)             |
| 75–79        | 18 (1.6%)             | 583 (52.8%)                 | 407 (36.8%)           | 79 (7.1%)          | 18 (1.6%)             |
| ≥ 80         | 4 (1.1%)              | 202 (56.7%)                 | 114 (32.0%)           | 33 (9.3%)          | 3 (0.8%)              |
| <b>Total</b> | 1873 (4.7%)           | 24 356 (61.5%)              | 9505 (24.0%)          | 2712 (6.8%)        | 1151 (2.9%)           |

A00071-46).

2.4.2. Criteria

All participants completed the online ICF questionnaire twice at an interval of 2–3 weeks. The following physiological data were collected:

- i) Number of posterior functional units (PFU). A PFU is defined as a pair of posterior antagonist teeth with at least one contact area during chewing. The number of PFUs was assessed by asking participants to chew 1–2 cycles on 200-µm-thick articulating paper; the number of molars and premolars in the mandible with at least one colored mark gave the number of PFUs. The number of PFUs ranges from 0 to 10, and chewing efficiency was considered affected when it was 4 or less (Drancourt et al., 2022; El Osta et al., 2014, 2019b, 2022).
- ii) Salivary function. Unstimulated salivary flow was measured by asking participants to allow saliva to accumulate naturally in the mouth, and to spit it directly into a collection tube instead of swallowing over a period of 10 min. Stimulated salivary flow was measured by asking participants to chew a weighed piece of parafilm and spit saliva into a pre-weighed screw-capped cup every time they felt the need to swallow over a period of 5 min. The cups were weighed, and salivary flow rates were expressed in ml/min assuming that 1 g of saliva corresponds to 1 ml (Muñoz-González et al., 2019).
- iii) Chewing performance. Participants were invited to chew a two-colored-chewing gum for 20 chewing cycles. A digital image of

both sides of the resulting wafer was obtained under standard lighting conditions. Scanning the wafer on a flatbed scanner provided a standardized image. Variance of Hue (VOH) was applied to assess color mixing (Gonçalves et al., 2021; Schimmel et al., 2015).

All these criteria were combined to classify the participants into two categories: good versus poor oral health. Participants with poor oral health had resting salivary flow <0.25 ml/min; and/or stimulated salivary flow <1 ml/min; and/or a number of PFUs <7; and/or a chewing performance value < percentile 50 of Hue SD values. All other participants were considered to have good oral status.

2.4.3. Validity analyses of the ICF oral health online questionnaire

The internal consistency of the ICF items was assessed using Cronbach’s Alpha. The external consistency over time for the eleven ICF items was assessed using the intraclass correlation coefficient (ICC). Discriminant validity was evaluated by testing the associations between each of the five oral ingestion function items (biting, chewing, manipulation of food in the mouth, salivation and swallowing) and overall oral status (poor/good) using Chi-square tests and Fisher Exact tests.

3. Results

3.1. Validity of the ICF oral health online questionnaire

Cronbach’s Alpha ranged from 0.797 to 0.843 when the items



**Table 5**

Proportion of participants with impaired oral function and activity related to oral health-related quality of life (OHRQoL) (GOHAI score) and age compared to those without impairment as complementary probability.

| Categories of GOHAI <sup>a</sup> score   |                  | Low ≤50<br>Poor<br>OHRQoL | Moderate<br>OHRQoL<br>51–56<br>Moderate<br>OHRQoL | High<br>57–60<br>Very good<br>OHRQoL | p      |
|--|------------------|---------------------------|---|--------------------------------------|--------|
| n age <60 years                          |                  | 4943                      | 9409  | 9891                                 |        |
| n age ≥60 years                          |                  | 9078                      | 15 463  | 15 056                               |        |
| <b>Impairment for ICF items</b>          | <b>Age years</b> |                           |   |                                      |        |
| <i>Biting</i>                            | < 60             | 1409 (28.5%)              | 705 (7.5%)  | 153 (1.5%)                           | <0.001 |
|  | ≥ 60             | 2056 (49.7%)              | 859 (14.2%)                                       | 159 (3.1%)                           | <0.001 |
|  | Total            | 3465 (38.2%)              | 1564 (10.1%)                                      | 312 (2.1%)                           | <0.001 |
| <i>Chewing</i>                           | < 60             | 2465 (49.9%)              | 1742 (18.5%)                                      | 318 (3.2%)                           | <0.001 |
|  | ≥ 60             | 2489 (60.2%)              | 1273 (21.0%)                                      | 245 (4.7%)                           | <0.001 |
|  | Total            | 4954 (54.6%)              | 3015 (19.5%)                                      | 563 (3.7%)                           | <0.001 |
| <i>Manipulation of food in the mouth</i> | < 60             | 639 (12.9%)               | 179 (1.9%)  | 43 (0.4%)                            | <0.001 |
|  | ≥ 60             | 970 (23.5%)               | 191 (3.2%)  | 32 (0.6%)                            | <0.001 |
|  | Total            | 1609 (17.7%)              | 370 (2.4%)  | 75 (0.5%)                            | <0.001 |
| <i>Salivation</i>                        | < 60             | 498 (10.1%)               | 519 (5.5%)  | 246 (2.5%)                           | <0.001 |
|  | ≥ 60             | 557 (13.5%)               | 489 (8.1%)  | 178 (3.4%)                           | <0.001 |
|  | Total            | 1055 (11.6%)              | 1008 (6.5%)                                       | 424 (2.8%)                           | <0.001 |
| <i>Swallowing</i>                        | < 60             | 715 (14.5%)               | 701 (7.5%)  | 306 (3.1%)                           | <0.001 |
|  | ≥ 60             | 794 (19.2%)               | 652 (10.8%)                                       | 234 (4.5%)                           | <0.001 |
|  | Total            | 1509 (16.6%)              | 1353 (8.7%)                                       | 540 (3.6%)                           | <0.001 |
| <i>Caring for teeth</i>                  | < 60             | 1396 (28.2%)              | 1115 (11.9%)                                      | 265 (2.7%)                           | <0.001 |
|  | ≥ 60             | 1082 (26.2%)              | 499 (8.2%)  | 111 (2.1%)                           | <0.001 |
|  | Total            | 2478 (27.3%)              | 1614 (10.4%)                                      | 376 (2.5%)                           | <0.001 |
| <i>Eating</i>                            | < 60             | 357 (7.2%)                | 111 (1.2%)  | 26 (0.3%)                            | <0.001 |
|  | ≥ 60             | 442 (10.7%)               | 92 (1.5%)   | 23 (0.4%)                            | <0.001 |
|  | Total            | 799 (8.8%)                | 203 (1.3%)  | 49 (0.3%)                            | <0.001 |
| <i>Drinking</i>                          | < 60             | 131 (2.7%)                | 80 (0.9%)   | 30 (0.3%)                            | <0.001 |
|  | ≥ 60             | 92 (2.2%)                 | 68 (1.1%)   | 29 (0.6%)                            | <0.001 |
|  | Total            | 223 (2.5%)                | 148 (1.0%)  | 59 (0.4%)                            | <0.001 |
| <i>Looking after one's health</i>        | < 60             | 1476 (29.9%)              | 1886 (20.0%)                                      | 1169 (11.8%)                         | <0.001 |
|  | ≥ 60             | 868 (21.0%)               | 688 (11.4%)                                       | 345 (6.7%)                           | <0.001 |
|  | Total            | 2344 (25.8%)              | 2574 (16.6%)                                      | 1514 (10.1%)                         | <0.001 |
| <i>Preparing meals</i>                   | < 60             | 947 (19.2%)               | 1397 (14.8%)                                      | 936 (9.5%)                           | <0.001 |
|  | ≥ 60             | 425 (10.3%)               | 348 (5.7%)  | 152 (2.9%)                           | <0.001 |
|  | Total            | 1372 (15.1%)              | 1745 (11.3%)                                      | 1088 (7.2%)                          | <0.001 |
| <i>Speaking</i>                          | < 60             | 541 (10.9%)               | 503 (5.3%)  | 247 (2.5%)                           | <0.001 |
|  | ≥ 60             | 540 (13.1%)               | 377 (6.2%)  | 136 (2.6%)                           | <0.001 |

**Table 5 (continued)**

| Categories of GOHAI <sup>a</sup> score |                           |   |                                      |        |
|--|---------------------------|---|--------------------------------------|--------|
|  | Low ≤50<br>Poor<br>OHRQoL | Moderate<br>OHRQoL<br>51–56<br>Moderate<br>OHRQoL | High<br>57–60<br>Very good<br>OHRQoL | p      |
| Total                                  | 1081 (11.9%)              | 880 (5.7%)  | 383 (2.5%)                           | <0.001 |

<sup>a</sup> General Oral Health Assessment Index.

‘biting’ or ‘drinking’ were deleted, respectively. The corrected item-total correlation varied from 0.117 (for drinking) to 0.693 (for biting). The calculated Cronbach’s alpha was 0.832, indicating good internal consistency. ICC values ranged from 0.377 for ‘drinking’ to 0.905 for ‘eating,’ indicating good external consistency for most items. ICF successfully identified the oral functioning of the participants. Individuals who reported more difficulty with items such as ‘biting’, ‘chewing’, ‘manipulation of food in the mouth’, and ‘salivation’ exhibited poorer oral status and chewing performance than participants reporting no difficulties for each item (p < 0.001).

**3.2. Study population**

Among the 40 542 participants in the NutriNet-Santé who completed the oral function questions, 945 subjects were excluded because of missing or outlying values. The final sample included 39 597 individuals with a mean age of 53.09 ± 14.14 years (75.8% women). The socio-demographic characteristics and study criteria variables of the study population are presented in Table 3.

**3.3. Changes in oral functioning with age**

The frequency of participants with impairment by age for all eleven ICF items are shown in Fig. 1. The prevalence of individuals with impairment for the five ICF items related to ingestion function (biting, chewing, manipulation of food, salivation and swallowing) and also for three activity items (eating, drinking and speaking) increased significantly with age (p < 0.001). The prevalence of impairments in ingestion function and activities (eating, drinking and speaking) was highest in people aged 80 or over (p < 0.001). The items ‘looking after one’s health’ and ‘preparing meals’ displayed higher values between 18 and 29 years, then decreased until 65–69 years and finally increased significantly after 70 years (p < 0.001). There was no significant difference by age for the item “caring for teeth” (p = 0.103). Moreover, no significant difference was observed in the variation of impairment prevalence within age categories between men and women.

The GOHAI score was significantly related to age (p < 0.001) (Fig. 2). The percentage of participants with a GOHAI score of 50 or less, indicating poor OHRQoL, increased significantly with age, and simultaneously the percentage of participants with a GOHAI score of 57 or more, indicating good oral health, decreased significantly (p < 0.001).

Mean values of perception of xerostomia varied with age, with lower values between 40 and 74 years (Fig. 3).

BMI was significantly related to age (p < 0.001) (Table 4). The percentage of participants with a BMI >25 was higher in those aged ≥60 years (41.8%) than in those aged <60 years (28.5%) (p < 0.001).

**3.4. Factors affecting impairment of oral function**

**3.4.1. Oral health related quality of life**

Each ICF item was significantly associated with the GOHAI score (p < 0.001). The percentage of participants with impairment for each ICF item was significantly higher when the GOHAI score was 50 or less, intermediate for a GOHAI score between 51 and 56, and lower for a

**Table 6**  
Xerostomia Inventory (XI) mean score in relation to the presence or absence of impaired oral function and activity, and age (N = 39 597).

| Impairment for ICF items          | Age years | Mean XI score ± Std. Deviation |               |        |
|-----------------------------------|-----------|--------------------------------|---------------|--------|
|                                   |           | No impairment                  | Impairment    | p      |
| Biting                            | < 60      | 18.92 ± 4.980                  | 21.52 ± 6.353 | <0.001 |
|                                   | ≥ 60      | 18.47 ± 5.166                  | 21.03 ± 6.236 | <0.001 |
|                                   | Total     | 18.76 ± 5.1                    | 21.24 ± 6.3   | <0.001 |
| Chewing                           | < 60      | 18.77 ± 4.892                  | 20.88 ± 5.990 | <0.001 |
|                                   | ≥ 60      | 18.34 ± 5.136                  | 20.79 ± 6.042 | <0.001 |
|                                   | Total     | 18.61 ± 5.0                    | 20.84 ± 6.0   | <0.001 |
| Manipulation of food in the mouth | < 60      | 19.04 ± 5.038                  | 22.63 ± 7.333 | <0.001 |
|                                   | ≥ 60      | 18.69 ± 5.254                  | 22.45 ± 6.909 | <0.001 |
|                                   | Total     | 18.91 ± 5.1                    | 22.52 ± 7.1   | <0.001 |
| Salivation                        | < 60      | 18.72 ± 4.701                  | 27.31 ± 6.550 | <0.001 |
|                                   | ≥ 60      | 18.33 ± 4.864                  | 26.43 ± 6.726 | <0.001 |
|                                   | Total     | 18.57 ± 4.8                    | 26.88 ± 6.7   | <0.001 |
| Swallowing                        | < 60      | 18.74 ± 4.762                  | 24.79 ± 6.863 | <0.001 |
|                                   | ≥ 60      | 18.34 ± 4.967                  | 24.15 ± 6.708 | <0.001 |
|                                   | Total     | 18.59 ± 4.8                    | 24.47 ± 6.8   | <0.001 |
| Caring for teeth                  | < 60      | 18.88 ± 5.025                  | 21.34 ± 5.807 | <0.001 |
|                                   | ≥ 60      | 18.74 ± 5.367                  | 20.91 ± 6.088 | <0.001 |
|                                   | Total     | 18.83 ± 5.2                    | 21.18 ± 5.9   | <0.001 |
| Eating                            | < 60      | 19.08 ± 5.088                  | 23.43 ± 7.343 | <0.001 |
|                                   | ≥ 60      | 18.87 ± 5.406                  | 21.88 ± 6.857 | <0.001 |
|                                   | Total     | 19.00 ± 5.2                    | 22.61 ± 7.1   | <0.001 |
| Drinking                          | < 60      | 19.11 ± 5.122                  | 24.80 ± 7.349 | <0.001 |
|                                   | ≥ 60      | 18.93 ± 5.441                  | 23.31 ± 7.614 | <0.001 |
|                                   | Total     | 19.04 ± 5.2                    | 24.15 ± 7.5   | <0.001 |
| Looking after one's health        | < 60      | 18.71 ± 4.947                  | 21.14 ± 5.683 | <0.001 |
|                                   | ≥ 60      | 18.61 ± 5.287                  | 21.58 ± 6.185 | <0.001 |
|                                   | Total     | 18.67 ± 5.1                    | 21.27 ± 5.8   | <0.001 |
| Preparing meals                   | < 60      | 18.82 ± 5.016                  | 21.39 ± 5.640 | <0.001 |
|                                   | ≥ 60      | 18.77 ± 5.368                  | 22.29 ± 6.304 | <0.001 |
|                                   | Total     | 18.80 ± 5.2                    | 21.59 ± 5.8   | <0.001 |
| Speaking                          | < 60      | 18.98 ± 5.035                  | 22.53 ± 6.416 | <0.001 |
|                                   | ≥ 60      | 18.74 ± 5.331                  | 22.25 ± 6.526 | <0.001 |
|                                   | Total     | 18.88 ± 5.2                    | 22.41 ± 6.5   | <0.001 |

GOHAI score of 57 or more, and this was true for individuals <60 years (p < 0.001) and for those ≥60 years (p < 0.001) (Table 5).

### 3.4.2. Xerostomia

In addition, each ICF item was significantly associated with XI (p < 0.001). The mean XI score was higher for participants with impairment on each of the ICF items compared to those without impairment, and this was true for individuals <60 years (p < 0.001) and for those ≥60 years (p < 0.001) (Table 6).

## 3.5. Impact of impairment on food avoidance and BMI

### 3.5.1. BMI

Each ICF item relating to ingestion function was significantly associated with BMI (p < 0.001); the percentage of participants with impairment for each of the ICF items relating to ingestion function increased significantly with BMI for individuals under 60 years (p < 0.001) and for those 60 years of age or older (p < 0.001). The percentage of participants with impairments in the items 'eating', 'looking after one's health', 'preparing meals' increased significantly with BMI for individuals under 60 years (p < 0.001) and for those aged 60 years or older (p < 0.001). The percentage of participants with impairment for the items related to 'caring for teeth' (p < 0.001), 'drinking' (p = 0.630) and 'speaking' (p = 0.596) were not significantly associated with BMI (Table 7).

### 3.5.2. Impact of impairment on food avoidance

Each ICF item relating to ingestion function was significantly associated with avoidance of meat, raw vegetables and crusty bread due to difficulties chewing or swallowing in participants <60 years (p < 0.001) and ≥60 years (p < 0.001). The prevalence of impairment was significantly higher in participants not eating these foods due to chewing or swallowing difficulties compared to others (Tables 8 and 9).

## 3.6. Increasing risks for frailty

Table 10 outlines how ingestion function, OHRQoL and xerostomia changed in older people. Those aged 80 years or older were 2.3 times more likely to have impaired chewing function than those aged 60–79 years. In addition, those aged 80 years or older were 1.5 times more likely to have impaired chewing function, 2.2 times more likely to have impaired salivation, 2.1 times more likely to have impaired swallowing function, and 1.9 times more likely to have impaired manipulation of food in the mouth, compared with those aged 60–79 years. Concurrently, those aged 80 years or older were 1.3 times more likely to have poor OHRQoL than those aged 60–79 years. Similarly, physical function and xerostomia were significantly affected after 80 years compared with those aged 60–79 years, but the strength of the association was weak (r = -0.048 for GOHAI physical function; r = 0.059 for xerostomia inventory).

## 4. Discussion

This study is the first to describe age-related impairment in ingestion function and related activities and participation of individuals living in an industrialized country in a large, population-based sample. Overall, 21.5% and 13.5% of the study population had chewing and/or biting impairments respectively. These results raise individual and population-based issues. Indeed, alterations in oral function vary with age and may affect food selection and consumption, thereby increasing the risk of non-communicable diseases (Benzian et al., 2012). Compared with other subjective indicators, such as the OHIP (Bugone et al., 2019) and GOHAI (El Osta et al., 2014; 2019b), which have been commonly used in nutritional studies, use of ICF-based questions enabled identification of individuals with oral impairment from a bio-psycho-social and person-centered approach (Dougall et al., 2015; World Health Organisation, 2001). Specific impairments in biting, sucking, chewing, salivation and swallowing can also be considered independently in the models used to calculate feeding capacity scores (Laguna et al., 2015; Sarkar, 2019). This can lead to a more specific and individualized assessment of oral functioning that targets individual experience. The use of a common framework that can be understood by all oral health and food technology disciplines would enhance interdisciplinary communication and collaboration, thereby improving understanding of oral food processing and its impact on nutrition. This study enabled the validation of online data collection of the ICF questionnaire when used to describe the oral



**Table 7**

Proportion of participants with impaired oral function and activity in relation to Body Mass Index (BMI) and age (N = 39,597) – a comparison with those without impairment as complementary probability.

| Categories of BMI kg/m <sup>2</sup>      |                  | <18.5       | 18.5–24.99   | 25–29.99     | 30–34.99    | ≥35         | p      |
|--|------------------|-------------|--------------|--------------|-------------|-------------|--------|
| n age <60 years                          |                  | 1454        | 15 854       | 4831         | 1415        | 689         |        |
| n age ≥60 years                          |                  | 419         | 8502         | 4674         | 1297        | 462         |        |
| <b>Impairment for ICF items</b>          | <b>Age years</b> |             |              |              |             |             |        |
| <i>Biting</i>                            | < 60             | 154 (10.6%) | 1326 (8.4%)  | 509 (10.5%)  | 171 (12.1%) | 107 (15.5%) | <0.001 |
|  | ≥ 60             | 83 (19.8%)  | 1585 (18.6%) | 993 (21.2%)  | 311 (24.0%) | 102 (22.1%) | <0.001 |
|  | Total            | 237 (12.7%) | 2911 (12.0%) | 1502 (15.8%) | 482 (17.8%) | 209 (18.2%) | <0.001 |
| <i>Chewing</i>                           | < 60             | 279 (19.2%) | 2740 (17.3%) | 1003 (20.8%) | 325 (23.0%) | 178 (25.8%) | <0.001 |
|  | ≥ 60             | 114 (27.2%) | 2095 (24.6%) | 1261 (27.0%) | 387 (29.8%) | 150 (32.5%) | <0.001 |
|  | Total            | 393 (21.0%) | 4835 (19.9%) | 2264 (23.8%) | 712 (26.3%) | 328 (28.5%) | <0.001 |
| <i>Manipulation of food in the mouth</i> | < 60             | 65 (4.5%)   | 486 (3.1%)   | 194 (4.0%)   | 73 (5.2%)   | 43 (6.2%)   | <0.001 |
|  | ≥ 60             | 32 (7.6%)   | 606 (7.1%)   | 371 (7.9%)   | 131 (10.1%) | 53 (11.5%)  | <0.001 |
|  | Total            | 97 (5.2%)   | 1092 (4.5%)  | 565 (5.9%)   | 204 (7.5%)  | 96 (8.3%)   | <0.001 |
| <i>Salivation</i>                        | < 60             | 85 (5.8%)   | 764 (4.8%)   | 245 (5.1%)   | 109 (7.7%)  | 60 (8.7%)   | <0.001 |
|  | ≥ 60             | 35 (8.4%)   | 663 (7.8%)   | 351 (7.5%)   | 117 (9.0%)  | 58 (12.6%)  | 0.001  |
|  | Total            | 120 (6.4%)  | 1427 (5.9%)  | 596 (6.3%)   | 226 (8.3%)  | 118 (10.3%) | <0.001 |
| <i>Swallowing</i>                        | < 60             | 140 (9.6%)  | 1016 (6.4%)  | 350 (7.2%)   | 126 (8.9%)  | 90 (13.1%)  | <0.001 |
|  | ≥ 60             | 57 (13.6%)  | 912 (10.7%)  | 486 (10.4%)  | 156 (12.0%) | 69 (14.9%)  | <0.001 |
|  | Total            | 197 (10.5%) | 1928 (7.9%)  | 836 (8.8%)   | 282 (10.4%) | 159 (13.8%) | <0.001 |
| <i>Caring for teeth</i>                  | < 60             | 193 (13.3%) | 1726 (10.9%) | 569 (11.8%)  | 186 (13.1%) | 102 (14.8%) | <0.001 |
|  | ≥ 60             | 34 (8.1%)   | 951 (11.2%)  | 495 (10.6%)  | 156 (12.0%) | 56 (12.1%)  | 0.156  |
|  | Total            | 227 (12.1%) | 2677 (11.0%) | 1064 (11.2%) | 342 (12.6%) | 158 (13.7%) | 0.004  |
| <i>Eating</i>                            | < 60             | 37 (2.5%)   | 267 (1.7%)   | 120 (2.5%)   | 49 (3.5%)   | 21 (3.0%)   | <0.001 |
|  | ≥ 60             | 6 (1.4%)    | 294 (3.5%)   | 176 (3.8%)   | 55 (4.2%)   | 26 (5.6%)   | <0.001 |
|  | Total            | 43 (2.3%)   | 561 (2.3%)   | 296 (3.1%)   | 104 (3.8%)  | 47 (4.1%)   | <0.001 |
| <i>Drinking</i>                          | < 60             | 20 (1.4%)   | 130 (0.8%)   | 59 (1.2%)    | 23 (1.6%)   | 9 (1.3%)    | 0.003  |
|  | ≥ 60             | 5 (1.2%)    | 106 (1.2%)   | 52 (1.1%)    | 17 (1.3%)   | 9 (1.9%)    | 0.630  |
|  | Total            | 25 (1.3%)   | 236 (1.0%)   | 111 (1.2%)   | 40 (1.5%)   | 18 (1.6%)   | 0.026  |
| <i>Looking after one's health</i>        | < 60             | 227 (15.6%) | 2501 (15.8%) | 1110 (23.0%) | 432 (30.5%) | 261 (37.9%) | <0.001 |
|  | ≥ 60             | 31 (7.4%)   | 742 (8.7%)   | 651 (13.9%)  | 326 (25.1%) | 151 (32.7%) | <0.001 |
|  | Total            | 258 (13.8%) | 3243 (13.3%) | 1761 (18.5%) | 758 (27.9%) | 412 (35.8%) | <0.001 |
| <i>Preparing meals</i>                   | < 60             | 222 (15.3%) | 2009 (12.7%) | 663 (13.7%)  | 238 (16.8%) | 148 (21.5%) | <0.001 |
|  | ≥ 60             | 30 (7.2%)   | 447 (5.3%)   | 270 (5.8%)   | 120 (9.3%)  | 58 (12.6%)  | <0.001 |
|  | Total            | 252 (13.5%) | 2456 (10.1%) | 933 (9.8%)   | 358 (13.2%) | 206 (17.9%) | <0.001 |
| <i>Speaking</i>                          | < 60             | 92 (6.3%)   | 793 (5.0%)   | 271 (5.6%)   | 89 (6.3%)   | 46 (6.7%)   | 0.017  |
|  | ≥ 60             | 33 (7.9%)   | 586 (6.9%)   | 303 (6.5%)   | 98 (7.6%)   | 33 (7.1%)   | 0.596  |
|  | Total            | 125 (6.7%)  | 1379 (5.7%)  | 574 (6.0%)   | 187 (6.9%)  | 79 (6.9%)   | 0.021  |

health of people aged over 65. It showed good internal and external consistency and was able to identify older people according to their oral functioning.

The prevalence of persons with impairment varied significantly with age, but the direction of the variation differed by item. The proportion of people with impairment increased significantly for oral function and for activities directly related to food oral processing, such as biting, chewing, manipulation of food in the mouth, salivation, swallowing, eating and drinking. These impairments are likely to affect the nutritional status of older persons. Previous studies have shown that older adults with poor oral health may modify their diets by gradually excluding hard-to-chew foods such as meat, fresh fruit, or vegetables (Allen, 2005; Bradbury et al., 2008; Cousson et al., 2012; Sheiham et al., 2001; Veyrone et al., 2007; Xu et al., 2019). This study reports that the prevalence of food oral processing impairment and with the avoidance of certain food increases with BMI. The soft foods preferred by people with impaired oral function and restricted activities are characterized by a high carbohydrate content, and a low fiber, mineral and protein content, which could partly explain the increase of BMI with age (Brownie, 2006).

Variation in the prevalence of impairment in the participation items 'preparing meals' and 'looking after one's health', characterized by a decrease at middle age, were not expected and deserve to be discussed. It might be suggested that factors influencing these variations differ according to age group. Activities such as meal preparation and health care may be associated to advanced age, with an expected increase in cognitive and motor impairments. However, the observation of this phenomenon in middle age was unexpected and require further research.

In younger people, other factors could explain the higher prevalence of restrictions, such as lack of time, lack of resources, or competing childcare responsibilities for example. Sociocultural habits relating to food consumption, preparation of meals and self-care habits in younger generations need to be further explored to explain these differences.

This study reports that participants over 79 years were twice as likely to develop impairment in oral function compared to people aged 60–79 years, were at greater risk for xerostomia and had low GOHAI functional dimension scores. The ICF oral function and activities/participation items were sufficiently sensitive to describe the increase in impairment in the oldest age group. Frailty has been defined as a clinically recognizable state of increased vulnerability, resulting from the age-associated decline in reserve and function of multiple physiological systems, such as compromised ability to cope with daily or acute stressors (Xue, 2011). Frailty has been operationalized as an index of risk by counting the number of deficits accumulated over time, including disability, disease, physical and cognitive impairments, psychosocial risk factors, and geriatric syndromes (Fried & Walston, 1998). Impairment in oral function is an early sign of potential nutritional problems and disturbances in diet and energy balance. Weight loss associated with oral impairment can be considered a relevant and specific criterion for identifying transitions between frailty states (non-frail, prefrail, frail) (Gill et al., 2006; Kojima et al., 2019).

One of the limitations of the study is its cross-sectional design, preventing inference of causality. The sample, composed of self-selected and presumably health-literate volunteers, is not representative of the French population. Many volunteers were excluded from the analysis because of data completeness/quality issues. All these aspects suggest the possibility of a selection bias and impose caution when generalizing

**Table 8**

Prevalence of impaired ingestion function for participants not consuming meat because they found it difficult to chew or swallow and age (N = 39,597) – a comparison with those without impairment as complementary probability.

| No consumption of meat (red, white, poultry) because it is difficult to chew or swallow |                  |            |              |        |
|---|------------------|------------|--------------|--------|
|   |                  | Yes        | No           | p      |
| Frequency for <60 years   |                  | 14         | 24,229       |        |
| Frequency for ≥60 years   |                  | 24         | 15,330       |        |
| <b>Impairment for ICF items</b>   | <b>Age years</b> |            |              |        |
| <i>Biting</i>   | <60              | 5 (35.7%)  | 2262 (9.3%)  | 0.007  |
|   | ≥60              | 11 (45.8%) | 3063 (20.0%) | 0.004  |
|   | <b>Total</b>     | 16 (42.1%) | 5325 (13.5%) | <0.001 |
| <i>Chewing</i>  | <60              | 9 (64.3%)  | 4516 (18.6%) | <0.001 |
|   | ≥60              | 17 (70.8%) | 3990 (26.0%) | <0.001 |
|   | <b>Total</b>     | 26 (68.4%) | 8506 (21.5%) | <0.001 |
| <i>Manipulation of food in the mouth</i>  | <60              | 5 (35.7%)  | 856 (3.5%)   | <0.001 |
|   | ≥60              | 10 (41.7%) | 1183 (7.7%)  | <0.001 |
|   | <b>Total</b>     | 15 (39.5%) | 2039 (5.2%)  | <0.001 |
| <i>Salivation</i>   | <60              | 5 (35.7%)  | 1258 (5.2%)  | <0.001 |
|   | ≥60              | 4 (16.7%)  | 1220 (8.0%)  | 0.119  |
|   | <b>Total</b>     | 9 (23.7%)  | 2478 (6.3%)  | <0.001 |
| <i>Swallowing</i>   | <60              | 10 (71.4%) | 1712 (7.1%)  | <0.001 |
|   | ≥60              | 8 (33.3%)  | 1672 (10.9%) | 0.003  |
|   | <b>Total</b>     | 18 (47.4%) | 3384 (8.6%)  | <0.001 |
| No consumption of deli meat because it is difficult to chew or swallow                  |                  |            |              |        |
|   |                  | Yes        | No           | p      |
| Frequency for <60 years   |                  | 39         | 24,204       |        |
| Frequency for ≥60 years   |                  | 75         | 15,279       |        |
| <b>Impairment for ICF items</b>   | <b>Age years</b> |            |              |        |
| <i>Biting</i>   | <60              | 15 (38.5%) | 2252 (9.3%)  | <0.001 |
|   | ≥60              | 46 (61.3%) | 3028 (19.8%) | <0.001 |
|   | <b>Total</b>     | 61 (53.5%) | 5280 (13.4%) | <0.001 |
| <i>Chewing</i>  | <60              | 20 (51.3%) | 4505 (18.6%) | <0.001 |
|   | ≥60              | 57 (76.0%) | 3950 (25.9%) | <0.001 |
|   | <b>Total</b>     | 77 (67.5%) | 8455 (21.4%) | <0.001 |
| <i>Manipulation of food in the mouth</i>  | <60              | 8 (20.5%)  | 853 (3.5%)   | <0.001 |
|   | ≥60              | 31 (41.3%) | 1162 (7.6%)  | <0.001 |
|   | <b>Total</b>     | 39 (34.2%) | 2015 (5.1%)  | <0.001 |
| <i>Salivation</i>   | <60              | 7 (17.9%)  | 1256 (5.2%)  | 0.004  |
|   | ≥60              | 17 (22.7%) | 1207 (7.9%)  | 0.004  |
|   | <b>Total</b>     | 24 (21.1%) | 2463 (6.2%)  | <0.001 |
| <i>Swallowing</i>   | <60              | 10 (25.6%) | 1712 (7.1%)  | <0.001 |
|   | ≥60              | 24 (32.0%) | 1656 (10.8%) | <0.001 |
|   | <b>Total</b>     | 34 (29.8%) | 3368 (8.5%)  | <0.001 |

the results. Furthermore, a very small minority of the sample reported an impact on food selection, introducing a limitation in drawing conclusions about the potential effects of variations in oral function with age on food selection. We present these findings, acknowledging the limitation, as they suggest a potential outcome that could be further explored in a dedicated study designed for this purpose.

**Table 9**

Prevalence of impaired ingestion function for participants avoiding raw vegetables and crusty bread due to difficulty chewing or swallowing (N = 39,597) – a comparison with those without impairment as complementary probability.

| Avoidance of raw vegetables because they are difficult to chew or swallow |                  |            |              |        |
|---|------------------|------------|--------------|--------|
|   |                  | Yes        | No           | p      |
| Frequency for <60 years   |                  | 13         | 24,230       |        |
| Frequency for ≥60 years   |                  | 28         | 15,326       |        |
| <b>Impairment for ICF items</b>   | <b>Age years</b> |            |              |        |
| <i>Biting</i>   | <60              | 8 (61.5%)  | 2259 (9.3%)  | <0.001 |
|   | ≥60              | 19 (67.9%) | 3055 (19.9%) | <0.001 |
|   | <b>Total</b>     | 27 (65.9%) | 5314 (13.4%) | <0.001 |
| <i>Chewing</i>  | <60              | 9 (69.2%)  | 4516 (18.6%) | <0.001 |
|   | ≥60              | 20 (71.4%) | 3987 (26.0%) | <0.001 |
|   | <b>Total</b>     | 29 (70.7%) | 8503 (21.5%) | <0.001 |
| <i>Manipulation of food in the mouth</i>                                  | <60              | 5 (38.5%)  | 856 (3.5%)   | <0.001 |
|   | ≥60              | 14 (50.0%) | 1179 (7.7%)  | <0.001 |
|   | <b>Total</b>     | 19 (46.3%) | 2035 (5.1%)  | <0.001 |
| <i>Salivation</i>   | <60              | 2 (15.4%)  | 1261 (5.2%)  | 0.145  |
|   | ≥60              | 7 (25.0%)  | 1217 (7.9%)  | 0.005  |
|   | <b>Total</b>     | 9 (22.0%)  | 2478 (6.3%)  | <0.001 |
| <i>Swallowing</i>   | <60              | 3 (23.1%)  | 1719 (7.1%)  | 0.060  |
|   | ≥60              | 9 (32.1%)  | 1671 (10.9%) | 0.002  |
|   | <b>Total</b>     | 12 (29.3%) | 3390 (8.6%)  | <0.001 |
| Avoidance of crusty bread because it is difficult to chew or swallow      |                  |            |              |        |
|   |                  | Yes        | No           | p      |
| Frequency for <60 years   |                  | 13         | 24,230       |        |
| Frequency for ≥60 years   |                  | 18         | 15,336       |        |
| <b>Impairment for ICF items</b>   | <b>Age years</b> |            |              |        |
| <i>Biting</i>   | <60              | 7 (53.8%)  | 2260 (9.3%)  | <0.001 |
|   | ≥60              | 12 (66.7%) | 3062 (20.0%) | <0.001 |
|   | <b>Total</b>     | 19 (61.3%) | 5322 (13.5%) | <0.001 |
| <i>Chewing</i>  | <60              | 9 (69.2%)  | 4516 (18.6%) | <0.001 |
|   | ≥60              | 15 (83.3%) | 3992 (26.0%) | <0.001 |
|   | <b>Total</b>     | 24 (77.4%) | 8508 (21.5%) | <0.001 |
| <i>Manipulation of food in the mouth</i>                                  | <60              | 6 (46.2%)  | 855 (3.5%)   | <0.001 |
|   | ≥60              | 11 (61.1%) | 1182 (7.7%)  | <0.001 |
|   | <b>Total</b>     | 17 (54.8%) | 2037 (5.1%)  | <0.001 |
| <i>Salivation</i>   | <60              | 7 (53.8%)  | 1256 (5.2%)  | <0.001 |
|   | ≥60              | 4 (22.2%)  | 1220 (8.0%)  | 0.050  |
|   | <b>Total</b>     | 11 (35.5%) | 2476 (6.3%)  | <0.001 |
| <i>Swallowing</i>   | <60              | 6 (46.2%)  | 1716 (7.1%)  | <0.001 |
|   | ≥60              | 8 (44.4%)  | 1672 (10.9%) | <0.001 |
|   | <b>Total</b>     | 14 (45.2%) | 3388 (8.6%)  | <0.001 |

Nevertheless, the strengths of the study are the very large sample recruited from the general population, the use of oral function and quality indices with established validity, and statistical control for many potential confounders. The different health care systems and cultural dietary habits of industrialized countries could have an impact on the prevalence of oral impairment and its consequences on the nutritional status of impaired individuals. Further studies should be designed to investigate this hypothesis.

**Table 10**

Frailty effects on ingestion function, oral health-related quality of life, and xerostomia (N = 15 354).

| Dependent dichotomized variables         | 60–79 years n = 14 998        | ≥80 years n = 356         | OR; 95% confidence interval                      | OR adjusted for BMI; 95% confidence interval                     | OR adjusted for BMI and gender; 95% confidence interval                     |
|--|-------------------------------|---------------------------|--|--|---|
| <b>Impairment for ICF items</b>          |                               |                           |  |  |   |
| <i>Biting</i>                            | 2947 (19.6%)                  | 127 (35.7%)               | p < 0.001<br>OR = 2.3 [1.8; 2.8]                 | p < 0.001<br>OR = 2.3 [1.8; 2.8]                                 | p < 0.001<br>OR = 2.3 [1.8; 2.9]  |
| <i>Chewing</i>                           | 3883 (25.9%)                  | 124 (34.8%)               | p < 0.001<br>OR = 1.5 [1.2; 1.9]                 | p < 0.001<br>OR = 1.5 [1.2; 1.9]                                 | p < 0.001<br>OR = 1.5 [1.2; 1.9]  |
| <i>Manipulation of food in the mouth</i> | 1145 (7.6%)                   | 48 (13.5%)                | p < 0.001<br>OR = 1.9 [1.4; 2.6]                 | p < 0.001<br>OR = 1.9 [1.4; 2.6]                                 | p < 0.001<br>OR = 1.9 [1.4; 2.5]  |
| <i>Salivation</i>                        | 1171 (7.8%)                   | 53 (14.9%)                | p < 0.001<br>OR = 2.1 [1.5; 2.8]                 | p < 0.001<br>OR = 2.1 [1.5; 2.8]                                 | p < 0.001<br>OR = 2.2 [1.6; 3.0]  |
| <i>Swallowing</i>                        | 1610 (10.7%)                  | 70 (19.7%)                | p < 0.001<br>OR = 2.0 [1.6; 2.7]                 | p < 0.001<br>OR = 2.0 [1.6; 2.7]                                 | p < 0.001<br>OR = 2.1 [1.6; 2.7]  |
| <b>GOHAI<sup>a</sup></b>                 |                               |                           |  |  |   |
| <i>GOHAI score ≤ 50</i>                  | 4021 (26.8%)                  | 114 (32.0%)               | p = 0.029<br>OR = 1.3 [1.1; 1.6]                 | p = 0.030<br>OR = 1.3 [1.1; 1.6]                                 | p = 0.012<br>OR = 1.3 [1.1; 1.7]  |
| <b>Dependent continuous variables</b>    | <b>60–79 years n = 14,998</b> | <b>≥ 80 years n = 356</b> | <b>Mean difference; 95% confidence interval</b>  | <b>Adjusted mean difference for BMI; 95% confidence interval</b> | <b>Adjusted mean difference for BMI and gender; 95% confidence interval</b> |
| <i>Xerostomia Inventory score</i>        | 18.9 ± 5.5                    | 20.6 ± 5.8                | r = 0.046; p < 0.001<br>1.686 (1.109; 2.263)     | r = 0.046; p < 0.001<br>1.685 (1.108; 2.262)                     | r = 0.059; p < 0.001<br>2.101 (1.536; 2.263)                                |
| <b>GOHAI</b>                             |                               |                           |  |  |   |
| <i>Physical function</i>                 | 18.5 ± 2.1                    | 17.9 ± 2.5                | r = -0.046; p < 0.001<br>-0.659 (-0.884; -0.435) | r = -0.046; p < 0.001<br>-0.656 (-0.880; -0.431)                 | r = -0.048; p < 0.001<br>-0.678 (-0.902; -2.667)                            |
| <i>Pain and discomfort</i>               | 12.7 ± 1.9                    | 12.6 ± 1.9                | 0.182  | -  | -   |
| <i>Psychosocial impact</i>               | 21.9 ± 3.1                    | 21.7 ± 3.0                | 0.173  | -  | -   |

<sup>a</sup> General Oral Health Assessment Index.

## Disclaimers

The opinions expressed in the article are ours and do not constitute an official position of the institutions.

## Ethical Statement for solid state ionics

Hereby, I/Nada EL OSTA, Corresponding author/consciously assure that for the manuscript/Age related impairments in ingestion from a large population based-sample/the following is fulfilled:

- 1) This material is the authors' own original work, which has not been previously published elsewhere.
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  - 3) The paper reflects the authors' own research and analysis in a truthful and complete manner.
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- The violation of the Ethical Statement rules may result in severe consequences.

## Funding

This work is part of ALIMASSENS Collaborative Project supported by the French National Research Agency (grant # ANR-14-CE20-0003). The NutriNet-Santé study is supported by the French Ministry of Solidarity and Health, the National Agency for Public Health (Santé Publique France), the National Institute for Health and Medical Research (INSERM), the National Institute for Agricultural Research (INRA), the National Conservatory of Arts and Crafts (CNAM).

## CRedit authorship contribution statement

**Martine Hennequin:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Data curation, Conceptualization. **Nada El Osta:** Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Marie-Laure Munoz-Sanchez:** Formal analysis. **Mathilde Vandenberghe Descamps:** Methodology, Data curation. **Valentina A. Andreeva:** Validation, Methodology, Investigation, Data curation. **Gilles Feron:** Methodology, Investigation, Data curation. **Emmanuel Nicolas:** Software, Methodology, Formal analysis, Data curation. **Bruno Pereira:** Software, Formal analysis, Data curation. **Marie-Agnès Peyron:** Methodology, Formal analysis. **Pierre-Yves Cousson:** Methodology, Investigation, Data curation. **Claire Sulmont-Rosse:** Data curation. **Denise Faulks:** Writing – review & editing, Validation, Methodology, Visualization.

## 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.

## Data availability

Data will be made available on request.

## Acknowledgment

We would like to thank all volunteers in the NutriNet-Santé cohort. The authors would like to thank Serge Hercberg who allows the access to the NutriNet-Santé cohort, and Chantal Septier for her contribution to the Alimassens study.

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