Influence of Age on Adaptability of Human Mastication

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Peyron, Marie-Agnès, Olivier Blanc, James P. Lund, and Alain Woda. Influence of age on adaptability of human mastication. J Neurophysiol 92: 773–779, 2004; 10.1152/jn.01122.2003. The objective of this work was to study the influence of age on the ability of subjects to adapt mastication to changes in the hardness of foods. The study was carried out on 67 volunteers aged from 25 to 75 yr (29 males, 38 females) who had complete healthy dentitions. Surface electromyograms of the left and right masseter and temporalis muscles were recorded simultaneously with jaw movements using an electromagnetic transducer. Each volunteer was asked to chew and swallow four visco-elastic model foods of different hardness, each presented three times in random order. The number of masticatory cycles, their frequency, and the sum of all electromyographic (EMG) activity in all four muscles were calculated for each masticatory sequence. Multiple linear regression analyses were used to assess the effects of hardness, age, and gender. Hardness was associated to an increase in the mean number of cycles and mean summed EMG activity per sequence. It also increased mean vertical amplitude. Mean vertical amplitude and mean summed EMG activity per sequence were higher in males. These adaptations were present at all ages. Age was associated with an increase of 0.3 cycles per sequence per year of life and with a progressive increase in mean summed EMG activity per sequence. Cycle and opening duration early in the sequence also fell with age. We concluded that although the number of cycles needed to chew a standard piece of food increases progressively with age, the capacity to adapt to changes in the hardness of food is maintained.

INTRODUCTION

The rhythm of mastication is generated by a brain stem central pattern generator (Dellow and Lund 1971), but its output is modulated by other parts of the brain and by the properties of food being processed, including the size, hardness, and texture of the pieces (Lund 1991; Peyron et al. 1997, 2002; Schindler et al. 1998; Thexton et al. 1980). Adaptation of the motor program to the physical characteristics of the food leads to changes in the amplitude and duration of electromyographic (EMG) activity, which in turn alter the duration and form of specific phases of the cycle (Schwartz et al. 1989; Thexton and Hiiemae 1997).

Little is known on the effect of aging on masticatory function. If confounding factors such as missing teeth are taken into account, aging alone has little impact on the ability of subjects to reduce food into small particles (Feldman et al. 1980; Fontijn-Tekamp et al. 2000; Hatch et al. 2001; Wayer and Chauncey 1983). In addition, the sizes of particles in a bolus judged to be ready to swallow by the subjects does not vary with age (Feldman et al. 1980). These findings are surprising because of the general progressive decline in total body muscle mass (Gallagher et al. 1997; Porter et al. 1995) and in muscle mechanical performance (Davies et al. 1986; Harridge et al. 1995) with aging. Furthermore, the cross-sectional areas of the masseters and medial pterygoids diminish in the elderly (Newton et al. 1987), and bite force also falls (Bakke et al. 1990; Hatch et al. 2001). These changes are accompanied by a reduction in salivation (Navazesh et al. 1992) and perhaps in reflex responsiveness (Kossioni and Karkazis 1998; Smith et al. 1991). Therefore we hypothesized that some age-related adaptation of masticatory function must occur to maintain masticatory performance.

Because physiological aging is frequently accompanied by the loss of teeth and by the development of local and systemic conditions that also reduce the ability to masticate (Hatch et al. 2001; Helkimo et al. 1977), we chose to evaluate the effects of physiological aging on mastication in relative isolation. A sample population of subjects aged 25–76 yr who had almost all their teeth and who had no evidence of systemic or oral disease was selected. Masticatory function was evaluated from the electromyographic (EMG) records of the masseter and temporalis muscles and from jaw movements recorded during the mastication of four elastic model foods of standard dimensions that differed in hardness.

METHODS

Subjects

Two advertisements were published in a local newspaper asking people with complete dentitions to volunteer for the study. The sample was made of 29 male (mean: 41.8 yr, from 25 to 73 yr) and 38 female (mean: 42.0 yr, from 28 to 71 yr) French-speaking Caucasians. Seven males and six females were >50 yr. To recruit an adequate number of subjects >50, we included those who had one or two missing teeth replaced by fixed bridges (2 males, 58 and 64 yr old; 3 females 54, 56, and 70 yr old). The quality of each prosthesis was evaluated, and the subject was accepted if the replaced tooth or teeth were in proper contact with those in the other dental arch. All our subjects were therefore considered to have a complete dentition. The relationship between upper and lower teeth was normal as assessed by standard dental criteria (Angle’s class I). None of the subjects had received orthodontic treatment. They were free of dental pathology such as caries or periodontal disease. They did not have orofacial pain, and no evidence of tenderness or joint pathology was detected during the physical examination. The subjects were not aware of tooth grinding or excessive tooth clenching. General health was good. None of the subjects were taking medications that affect muscle function, and they were not regular users of psychotropic drugs. This study was approved by the Ethics Committee of the Université d’Auvergne.

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Model foods

The test foods were four artificial products that varied in viscoelastic properties. They were manufactured in laboratory from four types of gelatin (Rousselot 100, 150, 200, 250 blooms, Degussa Texturant Systems, Bappte, France) used in different quantities (22.5 g, 25, 33 and 41.5 g) together with glucose (132 g) sucrose (111 g) water (84 g), and citric acid (13 g) to make four products, H1, H2, H3, and H4 named in order of increasing hardness. The products resembled commercial elastic sweets in texture. The softest of our four muscles and simultaneous vertical jaw movements during chewing of the hardest product (H4). The beginning and end of each EMG burst and the different phases of each cycle were determined by the algorithms described in Peyron et al. (2002). Because we have already shown that there is no effect of trial order on the parameters of mastication during a session (Lassauzay et al. 2000), the data obtained from mastication of the three samples of each test food were pooled. The following parameters were calculated from the EMG signals for each masticatory sequence (from the 1st opening until swallowing): the number of masticatory cycles, the mean frequency of mastication (number of cycles/division of sequence), the mean EMG activity per cycle and per muscle, and the summed EMG activities of the four muscles. The mean EMG activity per cycle and per muscle was named EMG activity per cycle and the summed EMG activities of the four muscles was named EMG activity per sequence. From the movement records, we measured cycle duration and duration of the opening, fast and slow closing phases (during the slow closing, the teeth are in contact with the food bolus), and the maximum vertical and lateral amplitudes for each cycle. We calculated means for each of these parameters for three series of three cycles that we chose in an earlier study because they represent the three main stages of the masticatory sequence: cycles 2–4 (series I), the three cycles in the middle of the sequence (series II), and the three last cycles (series III) (Peyron et al. 2002). Using SAS (version 6.12 software, SAS Institute), multiple linear regression analyses with stepwise forward variable selection were then carried out to assess the relative importance of age, gender, and hardness, to the masticatory parameters.

Recording EMG signal and jaw movement

The skin over the left and right masseter and anterior temporalis muscles was cleaned with soap, and bipolar surface electrodes for EMG were attached with adhesive disks. One electrode was placed over the lower third of the masseter, midway between the anterior and posterior borders, with a second two centimeters above it. The electrode over the anterior temporalis was placed just in front of the head of the subject was placed in a weak magnetic field. Displacement of the coils in the frontal plane induced a current that was recorded by electromagnets and amplified by an Ag101 system (Carstens, Göttingen, Germany), then acquired simultaneously with EMG signals on the Spike2 system. Programs written in Spike2 language were used to extract EMG data and kinematic parameters from the masticatory sequence.

Experimental protocol

The subjects were seated comfortably upright with the back of their heads supported and their feet insulated from the floor. They were asked to refrain from moving their heads during recordings. Two 60-min recording sessions were held for each subject. The first was a practice session to familiarize them with the experiment conditions, and only data from the second session was used in the analyses. Appointments were made ≥2 h after meals. During each session, the subject chewed three samples of each of the four products (total = 12) in random order. In addition, to reduce fatigue, the subject could speak, drink, or rest as he/she wished between each recording and he/she signaled when ready for the next sample. Each subject chose on which side of the jaw they would carry out unilateral mastication. To begin each trial, the sample was placed on the tongue by the experimenter. The subject then closed the teeth into occlusion, while keeping the sample between the tongue and the palate until the experimenter gave a signal to begin mastication. The food was chewed in a natural way and was then swallowed. The occlusal position served as a reference for the movement recording system.

Analysis of data

Figure 1 presents an example of rectified electromyograms for the four muscles and simultaneous vertical jaw movements during chewing of the hardest product (H4). The beginning and end of each EMG burst and the different phases of each cycle were determined by the algorithms described in Peyron et al. (2002). Because we have already shown that there is no effect of trial order on the parameters of mastication during a session (Lassauzay et al. 2000), the data obtained from mastication of the three samples of each test food were pooled. The following parameters were calculated from the EMG signals for each masticatory sequence (from the 1st opening until swallowing): the number of masticatory cycles, the mean frequency of mastication (number of cycles/division of sequence), the mean EMG activity per cycle and per muscle, and the summed EMG activities of the four muscles. The mean EMG activity per cycle and per muscle was named EMG activity per cycle and the summed EMG activities of the four muscles was named EMG activity per sequence. From the movement records, we measured cycle duration and duration of the opening, fast and slow closing phases (during the slow closing, the teeth are in contact with the food bolus), and the maximum vertical and lateral amplitudes for each cycle. We calculated means for each of these parameters for three series of three cycles that we chose in an earlier study because they represent the three main stages of the masticatory sequence: cycles 2–4 (series I), the three cycles in the middle of the sequence (series II), and the three last cycles (series III) (Peyron et al. 2002). Using SAS (version 6.12 software, SAS Institute), multiple linear regression analyses with stepwise forward variable selection were then carried out to assess the relative importance of age, gender, and hardness, to the masticatory parameters.

RESULTS

Effects of hardness, age, and gender on the whole sequence

Figure 2 shows the effects of hardness and age on four parameters in graphic form. The points represent data gathered for the softest (H1) and hardest foods (H4) for each subject. Regression lines were drawn for these two foods and also for H2 and H3. Linear regression analysis showed that the total number of cycles in a sequence (Fig. 2A) increased significantly with the hardness of food (P = 0.0001, Table 1) and with age (P = 0.0001, Table 1), but that gender was without effect (P = 0.202).

An increase of approximately four cycles was associated with a change to a harder food, and 0.3 cycles were added to the sequence per year of life >25 yr. Thus a food that needed 20 cycles to masticate at age 30 would need about 42 at age 70. However, mean masticatory frequency did not change with age, or with hardness of the test food (Fig. 2B), although the effect of gender was significant (P < 0.0001, Table 1). Women chewed at a slightly higher frequency than men (1.45 vs. 1.30 Hz).

The mean EMG activity per sequence also increased significantly with age and hardness of food and was significantly greater in men (Fig. 2C and Table 1). These effects were observed on each of the four muscles when they were considered individually. However, the mean EMG activity per cycle did not change with age, but it did vary significantly with food hardness (Fig. 2D). Figure 2 shows that there was a great deal of variation in the data. For instance, one subject took only four cycles to masticate H1, while another of similar age took >60. The linear regression models explained only a small fraction of the variance (10–25%, Table 1).

Effects of hardness, age, and gender on masticatory cycles

There were several significant effects of food hardness on movement parameters that were greatest early in the sequence.
Increasing hardness was associated with an increase in cycle duration of series I (Fig. 3A, Table 2) and in the duration of the opening and fast closing phases for series I (Fig. 3B) and series II. It was also associated with a significant increase in vertical amplitude for series I (Fig. 3C) and series II (Table 2). Cycle duration and duration of the opening phase of series I fell significantly with age (Fig. 3, A and B), but age had no effect on opening amplitude of cycles of series I (Table 3) or on movement parameters during the other two series. All cycles in the three series were significantly longer in duration in men, as
were the opening phases, and the closing phases for the first two series (Table 2). Maximum vertical opening amplitude was greater in men by more than 2 mm in all three series of cycles (Table 3).

The EMG data taken from the three series of cycles was consistent with the analysis of EMG activity during the whole sequence. There were significant effects of hardness on EMG burst area of all four muscles on the first two series of cycles but not in series III (Table 2). In Fig. 3D, we show the effect of hardness on the mean area of the chewing side masseter burst in series I. Table 2 shows that age had no significant effect on EMG activity whatever the muscle or the series. Gender had a significant influence on EMG activity of the three series only for non chewing masseter (Table 2).

**DISCUSSION**

Our results confirm that the number of cycles used by healthy human subjects to prepare a standard size piece of food for swallowing increases progressively with age (Feldman et al. 1980). In addition, we were able to show that even the elderly are able to compensate for changes in food hardness in the same way as younger subjects.

The design of the present study limits the interpretation of these findings. First we used a cross-sectional rather than...
longitudinal approach because it is not possible to follow subjects for decades. This means that we could not estimate the effects of any confounding variables that vary over time (e.g., changes in diet during wartime) and thus differentially influence the subjects. Second, we only recorded the activity of four muscles, and so the EMG data may not fully represent total masticatory muscle activity. Finally, we did not measure the size of particles in the bolus just before deglutition, so we cannot be sure that the efficiency of mastication remains constant over the years.

**TABLE 2.** Effects of food hardness, age, and gender on EMG and movement variables at different stages of the sequence

<table>
<thead>
<tr>
<th></th>
<th>Series I (Cycles 2–4)</th>
<th>Series II (3 Middle Cycles)</th>
<th>Series III (Last 3 Cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hardness</td>
<td>Age</td>
<td>Gender</td>
</tr>
<tr>
<td>EMG activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chew. temporalis</td>
<td>14.2***</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Non-chew. temporalis</td>
<td>18.1***</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Chew. masseter</td>
<td>19.6***</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Non-chew. masseter</td>
<td>20.3***</td>
<td>1.3*</td>
<td>5.2***</td>
</tr>
<tr>
<td>Movement variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening duration</td>
<td>2.9**</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Fast closing duration</td>
<td>4.4***</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Slow closing duration</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total cycle duration</td>
<td>4.2**</td>
<td>2*</td>
<td>7.3***</td>
</tr>
<tr>
<td>Vertical amplitude</td>
<td>5.3***</td>
<td>—</td>
<td>6.4***</td>
</tr>
<tr>
<td>Lateral amplitude</td>
<td>2.5*</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*R² values (%) for movement and EMG variables were drawn from multiple linear regression analyses of series I–III. The degree of significance is indicated by stars: ***P < 0.001; **P < 0.01; *P < 0.05. The constants were H₁, 25 yr of age, and men. Shaded cells correspond to a negative relation versus constant. Chew. and non-chew. indicate when considered muscle corresponded or not to the masticatory side.
Effects of gender

There was no difference between genders in the total number of cycles per sequence, but the mean frequency of mastication was slightly higher in males. The EMG activity per sequence was also higher in males. The amplitude of vertical jaw movements was less in women throughout the masticatory sequence. This finding of Karlsson and Carlsson (1990), who found that mean masticatory cycle frequency in young adults (mean age, 28 yr) was not significantly higher than in elderly subjects (mean age, 80 yr). As in our study, all their subjects had almost complete dentitions. Karlsson and Carlsson (1990) did find that vertical amplitude was lower in the older group, which seems to contradict our finding. However, the difference between their two groups could be due to the higher proportion of women in the older group (46 vs. 64%). Alternative explanations are the lower mean age of our population and differences in foods (elastic gels vs. Swedish crisp bread).

The area of the EMG bursts in the temporalis and masseter did not vary with age in our study despite the decrease of the maximal bite force that is known to occur (Bakke et al. 1990; Hatch et al. 2001; Helkimo et al. 1977). It is probable that maximum bite force falls because of a loss of muscle mass because Newton et al. (1987) found that the cross-sectional area of human masseter and medial pterygoid muscles decreases from 20 to 90 yr. Their data suggest that there is a progressive loss of muscle mass of ~40% over the age range of our subjects (25–75 yr). The fact that the mean burst area did not change with age suggests that the surface area of muscle fibers contracting during the burst is approximately constant during aging. If so, the proportion of motor units used during the chewing of a standard food product compared with the total available number of motor units must increase progressively with age, which suggests that the jaw closing muscles of older people are working closer to their maximum capacity than those of the young. However, it is also possible that the voltage of EMG signal recorded from the surface of the skin increases with age because of a gradual increase in skin resistance. Fujita et al. (2001) showed that skin impedance (opposition to the flow of AC) on the palm of the human hand rises with age. A similar age-related increases in the impedance of the abdominal skin of rats is due in part to an increase in skin thickness and decrease in water content (Ngawhirunpat et al. 2002). If resistance increases with age, then EMG burst area could remain constant despite a gradual fall in the current generated by the muscle (Ohm’s law).

Although the area of single EMG burst did not vary with age, the total amount of the EMG activity needed to prepare standard sized pieces of food for swallowing increased progressively with age because of the increase in the number of masticatory cycles. However, the effect was independent of the hardness of the food because the same number of additional cycles were added to the masticatory sequence with age for the softest and the hardest products. This strongly suggests that the increase in the number of cycles was not due to a lack of strength of the masticatory muscles. Another explanation must be sought. A decrease in mechanical efficiency of the teeth could not be caused, in our sample, by a loss of teeth with age because all subjects had complete dental arches. Although it is possible that the teeth become less efficient cutting instruments because of progressive wear, it is difficult to believe that this would reduce their efficiency so that the number of cycles should be increased by >50% from 25 to 75 yr. Indeed, Hatch et al. (2001) have shown that age alone has a negligible effect on the size of peanut particles obtained after 20 chewing strokes.

Effects of hardness

As we expected from an earlier study using similar test foods in young men (Peyron et al. 2002), there was a progressive increase in the number of cycles per sequence as the food increased in hardness. The effect of hardness on EMG values and movement parameters were very evident at the start of the masticatory sequence, when EMG bursts were greater with the harder foods in all muscles, the opening and closing phases were longer, and vertical amplitude was greater. However, by the end of the sequence, differences between food products were small and generally insignificant as was found in the previous study (Peyron et al. 2002).

Effects of age

We showed that there is a mean increase of about three cycles per sequence per 10 yr of life, and thus a 50% increase in total number cycles from 25 to 75 yr. Age has a small but significant effect on the duration of the early masticatory cycles, which increased by ~2% per year, but had no influence on cycles in the middle or end of the sequence. This age-related change in the duration of the earliest cycles was too small to be reflected in the mean frequency calculated from the EMG records, which did not change significantly with age. This is consistent with the finding of Karlsson and Carlsson (1990), who found that mean masticatory cycle frequency in young adults (mean age, 28 yr) was not significantly higher than in elderly subjects (mean age, 80 yr). As in our study, all their subjects had almost complete dentitions. Karlsson and Carlsson (1990) did find that vertical amplitude was lower in the older group, which seems to contradict our finding. However, the difference between their two groups could be due to the higher proportion of women in the older group (46 vs. 64%). Alternative explanations are the lower mean age of our population and differences in foods (elastic gels vs. Swedish crisp bread).

Effects of food hardness, age, and gender on the amplitude of jaw opening for the three series of masticatory cycles

<table>
<thead>
<tr>
<th>Series</th>
<th>Amplitude of opening</th>
<th>Estimated Values</th>
<th>Fisher Ratio</th>
<th>P</th>
<th>R²</th>
<th>Sum R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intercept</td>
<td>15.346</td>
<td>777</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardness</td>
<td>0.906</td>
<td>14</td>
<td>0.0003</td>
<td>0.053</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>—</td>
<td>—</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>—</td>
<td>—</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series I</td>
<td>Intercept</td>
<td>13.178</td>
<td>136</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td></td>
<td>Hardness</td>
<td>0.585</td>
<td>6</td>
<td>0.0119</td>
<td>0.026</td>
<td></td>
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<tr>
<td></td>
<td>Age</td>
<td>—</td>
<td>—</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>—</td>
<td>—</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series II</td>
<td>Intercept</td>
<td>14.136</td>
<td>172</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardness</td>
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<td>—</td>
<td>NS</td>
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</tr>
<tr>
<td></td>
<td>Age</td>
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<tr>
<td></td>
<td>Gender</td>
<td>—</td>
<td>—</td>
<td>NS</td>
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</tr>
</tbody>
</table>

Values were drawn from the multiple linear regression analyses. The constants were H₀, 25 yr of age, and men.
cycles. Perhaps features other than the mechanical degradation of the food requires more time and more cycles in the elderly. Manipulation of the food pieces by the tongue and cheeks to keep them between the teeth, then to form a bolus for swallowing, is a complex task that could require more time in the elderly. Also more cycles might have been needed to incorporate enough saliva into the bolus. Many elderly subjects suffer from xerostomia, and stimulated salivary flow and mucus concentration does diminish with age in apparently normal subjects (Denny et al. 1991; Navazesh et al. 1992).

The effects of age on muscle properties had little effect on the ability of our older subjects to adapt to changes in the hardness of the test foods. They were able to adjust the parameters of individual cycles in the same way as younger subjects, and approximately the same number of cycles and total EMG activity were added to the sequence by young and old subjects as the food got harder. Note that the slopes of the lines for the four foods relating age to cycle number and EMG activity per sequence were parallel (Fig. 2).

Because the hardnes of the hardest product reached only 5.5 on 10 unit Visual Analogue Scale, it is possible that we missed an age-related difference in ability to adapt that emerges only at high levels of work. Koyama et al. (2002) did show that a group of young subjects (mean age, 29 yr) continued to increase EMG output with increases in hardness of natural foods after older subjects (mean age, 67 yr) had reached a plateau. However, their groups differed greatly in gender distribution (young group: 57% male; old group: 30% male), and they did not match the groups for dental state.

Although we can make no direct comparisons to other motor systems, it would seem that, as long as people keep their teeth, the masticatory system is relatively well preserved. This is perhaps the result of the fact that this motor system is exercised daily, even by people who have difficulty walking. Furthermore, enthusiasm for this type of exercise usually increases as we grow old.

GRANTS

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