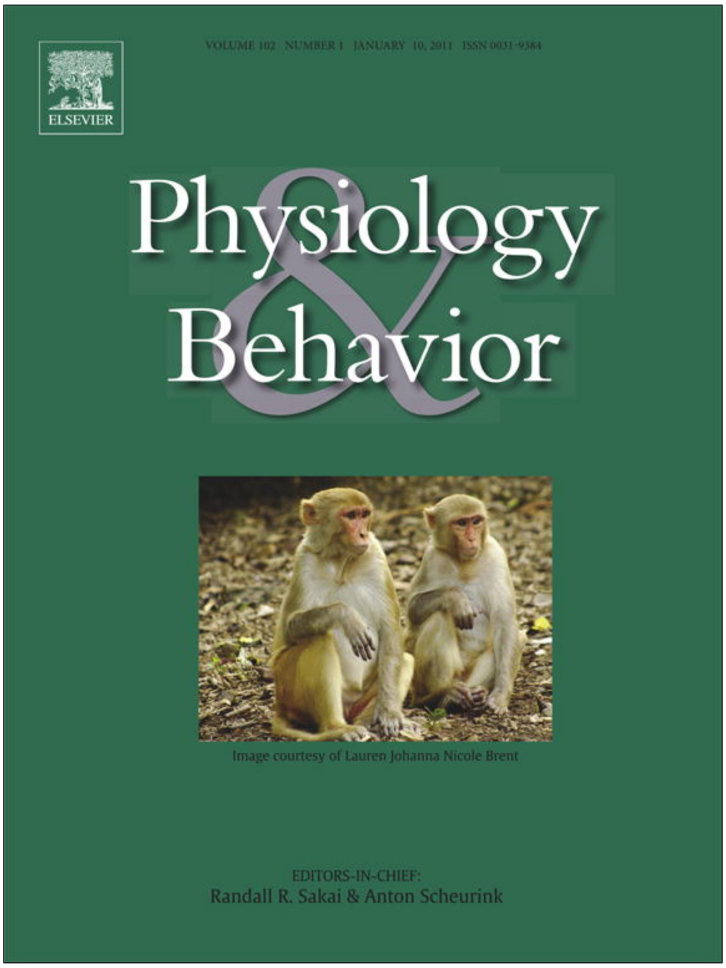

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Description of chewing and food intake over the course of a meal

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ABSTRACT

While the average frequency of chewing and food intake have been reported before, a detailed description of the pattern of chewing and the cumulative intake of food over the course of a meal have not. In order to achieve this goal, video recording of the maxillary–mandibular region of women eating food from a plate was synchronized with video recording of the plate and computer recording of the weight-loss of the plate. Video recording of chewing correlated strongly with chewing identified by magnetic tracking of jaw displacement in a test with chewing gum at three different frequencies, thus ensuring the validity of video recording of chewing. Weight-loss data were corrected by convolution algorithms, validated against human correction, using sliding window filtering to correct errors with video events as reference points. By use of this method, women ate on average 264 g of food over 114 min, they took an average of 51 mouthfuls during the meal and displayed on average 794 chews with 15 chews per chewing sequence. The number of mouthfuls decreased and the duration of the pauses after each mouthful increased in the middle of the meal and these measures were then restored. The ratio between chewing sequences and subsequent pauses remained stable although the weight of each mouthful decreased by the end of the meal, a measure that is hypothesized to be reflected in a decelerated speed of eating. The method allows this hypothesis to be tested and its implication for clinical intervention to be examined.

1. Introduction

The study of eating and drinking in animals has a long history [1] and the limitations of simple measures, e.g., amount of food and fluid consumed were identified early on [2]. As a consequence, more comprehensive methods to study the details, i.e., the microstructure of ingestive behavior, emerged [2–7].

1.1. Bursts of licking, pauses and cumulative fluid intake in rats

With continuous recording of intake of liquid diets, drinking in the rat was found to consist of bursts of licking and intervening pauses [8–13] (Fig. 1). Since licking during the bursts occurred at a stable rate, the cumulative water intake during each session was directly dependent on the duration of the bursts, the water ingested with each lick and the rate of licking [10,13]. Deprivation or addition of sugar to the liquid solution was subsequently found to affect the duration of the pauses, thereby changing the distribution of bursts into clusters during the period of ingestion as well as the frequency of licking within bursts [6,9,11,12]. Subsequently, describing the microstructural pattern of licking in rats provided with sugar-loaded liquid diets, clusters of bursts and pauses were analyzed to model the neurobiological processes engaged in the initiation and termination of licking [8,11,12].

1.2. Chewing sequences, pauses and cumulative food intake in humans

As noted earlier [7,10,14], human eating is similar to rat drinking, in that it consists of bursts of chews or chewing sequences (rather than bursts of licking) of mouthfuls of food (elsewhere referred to as bites), separated by pauses. Similarly, early studies using electromyography, yielded measures of the microstructure of eating, e.g., mouthfuls, chews and swallows [15–21]. Video recording of dinner meals, also used long ago [22], has been validated against the electromyography techniques [23] and it was pointed out that such non-invasive methods may provide more valid measures than electromyography [24]. Since mastication is a significant topic in dental science, methods to measure jaw movements were developed even longer ago [25,26]. More recently, magnetic jaw displacement detection has been used for detailed description of jaw movements after restoration of dental status [27]. In addition, portable equipment using sensors monitoring the sounds generated by chewing have been developed, although these have not yet been used extensively [28,29].

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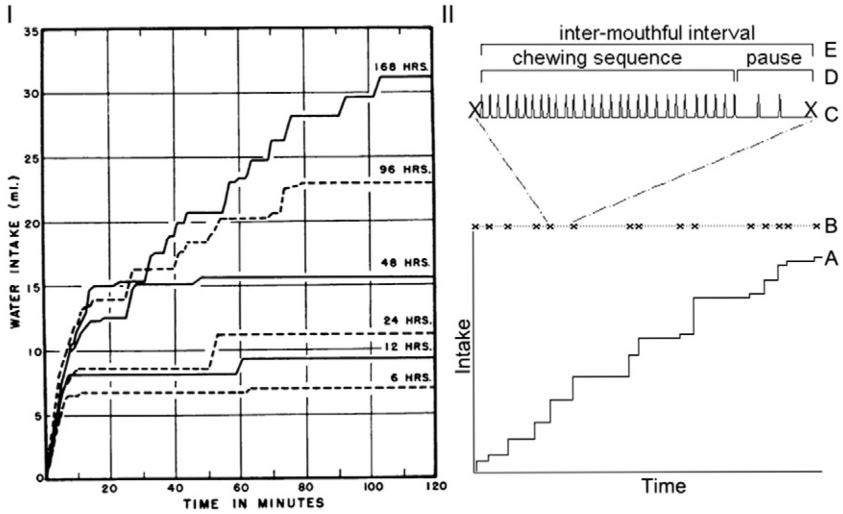

Fig. 1. I. Cumulative intake of water in rats as a function of prior water deprivation (reproduced with permission from Hill and Stellar, 1951). II. A. Cumulative intake of food in a woman based on data on the weight of food removed from a plate and recorded by a scale, B. Mouthfuls (x) based on data time-stamped from video recordings of the plate synchronized with data of removal of food from the plate and C. Chews time-stamped from video recordings of the maxillary–mandibular region. D. An uninterrupted series of chews constitutes a chewing sequence, followed by a pause with a few scattered, or no chews. E. A chewing sequence and a subsequent pause constitute an inter-mouthful interval.

Methods for measuring cumulative intake of liquid food in humans, similar to those used in the rat, were also developed early on [7,14]. More recently, the cumulative intake of solid food from a plate placed on a scale has been recorded by a computer both in research [30–35] and in the treatment of patients with eating disorders [36–38] and obesity [39]. A quadratic equation is fitted on the recorded weight-loss data, generating the cumulative intake curve (CIC): $y = kx^2 + lx$, where y is the amount of food ingested, x is the time and the k-coefficient is related to the change of the speed of eating over the course of the meal and the l-coefficient is related to the initial speed of eating [30–34,38,40]. CICs generated by humans with this method are conspicuously similar to the CICs generated by rats ingesting a liquid diet (Fig. 1). However, while vertical lines are measures of intake during bursts of licking in the rat, they are measures of the amount of food removed from the plate in the human, and while horizontal lines in the rat CIC indicate the duration of the pause between bursts of licking, they reflect the time spent chewing and pausing before the next mouthful in humans.

Thus, the human CIC is a measure of the amount of food removed from a plate over the course of the meal, not a measure of eating behavior, i.e., chewing and swallowing. To combine the two, we have developed a method to describe single meals reliably, quickly and in full detail. Such a procedure is important because of the differences between the CIC of under- and overweight patients [38], and because the CIC can be used to normalize the weights of both patient groups by using real-time feedback derived from the CIC of normal weight individuals during meals [37,39]. These patients also exhibit a range of cognitive and emotional changes which are likely influenced by the pattern of chewing [41].

While simultaneous recording of food intake and chewing has been attempted before, the results were inconclusive because the various temporal phases of the meal were not considered [42–44], invasive equipment and unnatural food items were used [19,20,24], or because details about the calculations used were not reported [33]. We believe that once the presented methodology is translated into clinical practise, it will contribute to an improved behavioral training program for weight management.

2. Material and methods

2.1. Subjects

Female volunteers were screened after having responded to advertisements placed on nearby university campuses. Inclusion criteria were having a general good health, including good dental health (i.e. no serious self-reported dental problems), a body mass index (BMI, weight/height squared, kg/m^2) between 18 and 25 and being between 18 and 25 years old, non-vegetarian and having no medical conditions or medication and no history of eating and anxiety disorders. Six women with a median age of 24.2 (range: 23.2–24.7) years and BMI of 23.5 (21.2–24.5) were studied for validating the video method using magnetic jaw displacement [27]. Eleven women with an age of 22.3 (18.1–24.8) years and a BMI of 22.3 (18.6–24.7) were studied for cumulative intake of food and chewing. We study women, as our goal is to understand and treat eating disorders, which mainly affect women. The women were informed that the study aimed at understanding human eating behavior, that the results would be useful in improving the treatment of patients who have lost control over body weight and that they could leave the study at any time without giving a reason. The procedures were approved by the Regional Central Ethical Review Board in Stockholm.

2.2. Procedure

2.2.1. Video data validation

On admission, six women were introduced into an electrically and magnetically shielded room, where they sat in a relaxed position. Initially, the participants were visually inspected by a trained dentist for absence of outstanding dental conditions. In the subsequent test session, they chewed a piece of peppermint flavoured chewing gum (Wrigley Scandinavia AB, Stockholm, Sweden) during 20 s. A digital video camera (DigitalCam, Samsung, Seoul, South Korea) was directed towards the woman's maxillary–mandibular region at an angle of about 40°. The video recordings were transferred to a PC for analysis after the session, as described in detail later. Simultaneously, the woman had a custom built, light-weight array of magnetic sensors attached to her head (Umeå University, Physiology Section, IMB, Umeå, Sweden); the equipment allows free movement of the head during mastication. The alternating position of a small magnet (10×5×5 mm), attached to the labial surfaces of the mandibular incisors, was tracked at a frequency of 800 Hz. All signals recorded were stored by using a microcomputer-based system (SC/ZOOM, v.3.1.02, Umeå University, Physiology Section, IMB, Umeå, Sweden); an experienced researcher determined the occurrence of chews and calculated the frequency of chewing [27].

Each woman participated in three sessions presented in random order. During one session, the women were instructed to chew the gum without constraints. During the other two sessions, they chewed guided by an acoustical signal generated by a metronome, set at 0.5 or 0.75 Hz, respectively [45]. These frequencies are significantly lower than previously reported default chewing frequencies [14,16,19,20,24,33]; higher frequencies were avoided as they are used to induce pain in model studies of temporo-mandibular joint disorders (e.g., [46]). Chewing gum, rather than food, was used, in order to make sure that both methods reliably detected chewing movements including an experimentally induced change in chewing frequency.

2.2.2. Meal analysis

A complete meal analysis was performed in the other 11 women. After an introductory meeting, the women were served three lunches separated by at least a week. No data were collected from the first lunch, which served to familiarize the women with the experimental environment and the procedure.

The women agreed to a certain breakfast time during the test days. The kind and the quantity of the breakfast were also prearranged (subject-specific), and the women abstained from eating and drinking (except water) afterwards, in an effort to minimize hunger variations. Lunches were served between 11:30 am and 1:00 pm and the same food was served throughout the study; precooked chicken and vegetables pieces (maximum weight per piece: 2.6 g and 1.2 g for chicken and vegetables respectively), heated in the oven and served as a homogenous mix on the plate (426 kJ, 10.7 g protein, 8.0 g carbohydrate and 2.5 g fat/100 g, Guldfågeln, Findus AB, Bjuv, Sweden). A sense of *ad libitum* availability of food was created by serving 1.5–2 kg of food on a big serving tray and informing the women that they were free to eat as much and as long as they wanted, by adding food on their plate (i.e., transferring food from the serving tray) anytime during the meal. Additionally, no restrictions were set concerning the amount of food left on the serving tray and plate at the end of the meal. The surface temperature of the food at the beginning of each meal, was approximately 50 °C, a temperature deemed "comfortable" for eating by the participants.

Meals took place individually, in a secluded room without windows to exclude social effects and achieve uniform lighting conditions, for optimal video recording. There were no reading materials, mobile phones or music during the meals.

Before and after the meal, the women filled in custom made questionnaires with visual analogue scales (0–100), rating mood, anxiety, appetite and palatability of the food. The questionnaires were used as screening material to identify inconsistencies in the women's emotional status or in the quality or presentation of the food. No meals were excluded from the analysis because of the results of these questionnaires. For example, the women estimated their hunger at a mean (SD) of 68 (13) and the palatability of the food at 76 (11), levels which we commonly note in other groups of women tested with the same procedures.

2.2.3. Data collection

Two types of data were collected:

Data on the weight-loss of a plate were obtained from a scale connected to a custom made computer, Mandometer® (Mikrodidakt, Lund, Sweden) [34], every second during the meal. The data files were transferred to a PC for analysis after the meal.

Data on mouthfuls, i.e., removal of food from the plate and placement of the food in the mouth, and chews, i.e., any maxillary–mandibular movement, in relation to the weight-loss of the plate were obtained using two digital video cameras (DigitalCam), placed roughly 2.5 m from the eating table. One camera was directed towards the plate and the other camera was directed towards the woman's maxillary–mandibular region as in the validation study. The video recordings were transferred to a PC for analysis after the meal.

2.2.4. Data analysis

2.2.4.1. Primary data processing. The video recordings were time-stamped manually, using a custom made, macro-program for Excel 7 (Microsoft, Seattle, WA, USA). The time after the initiation of the meal (initial removal of food from the plate) was measured with millisecond accuracy. The video recordings of the plate were time-stamped for occurrences of spoonfuls, i.e., removal of food from the plate and addition of food from the serving tray to the plate. The recordings of the maxillary–mandibular region were time-stamped for occurrences of mouthfuls and chews in half speed.

The spoonful and mouthful data series were synchronized (Excel 7, Microsoft), eliminating discrepancies between the series by filtering out unusual behaviors, e.g., double mouthfuls originating from the same spoonful (37 occurrences across the study, <1% of the total number of mouthfuls). As a result, one unified mouthful sequence for each meal was calculated and combined with the chewing data from the meal (Fig. 1).

2.2.4.1.1. Analysis of weight data. Initially, the weight data series were marked manually for the start (the second before the first mouthful) and the end of the meal (the second after the last mouthful) and for additions of food to the plate, using the video recordings of the area of the plate. The weight that was added to the plate was factored in the cumulative food intake, while the duration of the additions of food was treated as a pause, as no food intake or chewing occurred during these events.

Having previously dealt with similar datasets of weight-loss [34,38], we have identified all possible errors appearing during a meal. The errors emerge due to: A. Exertion of pressure on the plate during a spoonful preparation or placement of a utensil on the plate and B. Delay of recording of data due to memory buffer overload in Mandometers® (≤4 s).

An algorithm was written in Visual Basic 6, embedded in modular fashion into a customised, macro-enabled Excel 7 file, in order to automatically correct the data series. To confirm the validity of this method, algorithmically corrected data series were compared with data series corrected manually by two experienced researchers, unfamiliar with the purpose of our study.

2.2.4.1.2. Manual error correction. The researchers had been trained to read, interpret and manually correct weight data series generated by Mandometers®. Data from meals were presented to the researchers both as a numerical series and as an interactive graph marked with the occurrences of mouthfuls identified by the video recordings. Each researcher went through the data series and manually corrected the reduction of weight on each video-marked mouthful. They were also given access to the video recordings and were advised to consult the video feeds in order to identify and correctly resolve complicated data patterns recorded during the meal. The two researchers worked independently, each correcting the whole data set (22 meals).

2.2.4.1.3. Automated error correction. Each of the raw data series was fed into the modified Excel file, together with the unified mouthful sequence calculated from the video recordings; the video-timed mouthfuls were used as objective reference points in time for the algorithm calculations. The algorithm utilizes successive filters, each identifying and correcting different errors. Using the principle of sliding window filtering, used in convolution based algorithms (e.g., [47]), unique searching and correction parameters (adapted for the purpose of the present method for use on single-axis, discrete time series) were utilized for each of the filters, due to the unique nature of each expected error (Table 1, Appendix A).

Table 1
Characteristics of the algorithm for correction of weight-loss data series, with the help of manually time-stamped mouthfuls over the course of a meal.

Expected error	Expected data pattern	Search parameter(s)	Correction
Knife and/or fork on plate, no food consumption.	Rapid (≤2 s) increase in weight equal to 45/79/34 g, followed by rapid (≤2 s) decrease of the same weight. Event duration ≤16 s.	16 s sliding window analysis across the meal to identify entire event.	Exclusion of added weight.
Fork on plate, subsequent food consumption.	Rapid (≤2 s 34) g increase in weight, followed by rapid (≤2 s) 34+Xg decrease, X equals the weight of the mouthful.	As above	Exclusion of fork weight. The weight of the mouthful equals the difference of weight before and after the event.
Knife on plate while food is consumed.	Rapid (≤2 s) 45 g increase in weight. Subsequent smaller reductions in weight (≤18 g each). Rapid (≤2 s) 45 g decrease in weight.	As above	Exclusion of knife weight. Subsequent weight reductions are subtracted from the weight before the event.
Pressure on plate just before a mouthful.	Relatively short (≤4 s) peak (increase/decrease of weight ≤6 g), followed by a video-defined mouthful.	3 s upstream window before each video-defined mouthful.	Exclusion of peak. Mouthful weight equals absolute difference between weights before peak and after mouthful.
Food manipulation and/or pressure on table.	"Noise", i.e., increases and decreases in weight (2–4 s), adding to zero, followed by a video-defined mouthful.	6 s sliding window analysis, across data segments defined by 2 consecutive mouthfuls, to identify "noise".	Exclusion of nonsensical weight variations. Mouthful weight calculated as usual.
Data registration delay ≤4 s.	Short period of zero-variation (≤4 s), followed by mouthfuls in quick succession. The recorded "distance" between downstream events does not follow video defined timing.	4 s sliding window analysis across data segments, defined by 3 consecutive mouthfuls, to identify zero-variation periods.	Case 1: If the next recorded mouthful doesn't overlap with the zero-variation period, the mouthful weight is calculated as usual and is assigned to the video-defined timing of the mouthful occurrence. Case 2: In case of overlap, the first subsequent weight reduction is assigned to the video-defined previous mouthful.

2.2.4.2. Meta-analysis of data. Both the manually and the algorithmically corrected series of weight-loss data were reversed and transformed into series of intake to display increases in food intake over time. The intake series were synchronized with the series of data on mouthfuls and chews, thus providing a complete description of each meal (Fig. 1). The CIC described in the Introduction, was used to model the data series (Sigmaplot 11.0, Systat Software, Inc, Chicago, US).

2.2.4.3. Validation. The k- and l-coefficients of the CIC corrected by the two researchers were averaged across the two meals and then correlated between the two researchers and with the coefficients derived by the algorithm. We report the r-value for each correlation, as well as the statistical significance of the underlying regression model (Statistica 9.1, Statsoft, Tulsa, OK, USA).

2.2.4.4. Composite meals. The amount of food eaten, the duration of the meal, the number of mouthfuls, the weight of the mouthfuls, the number of chews and chews/chewing sequence were measured (Fig. 1 II). Thus, the number of mouthfuls equals the number of sequences. A chewing sequence was defined as an uninterrupted series of chews (pauses ≤2 s) that includes 95% of the chews of that mouthful, excluding the duration of the pause until the next mouthful. These criteria were selected after inspecting 100 inter-mouthful intervals, randomly selected out of all the meals in the study. Using an Excel 7 macro with a 2 s sliding window over each separate inter-mouthful interval, we located the end point of each sequence, allowing us to calculate the duration of the sequence and the subsequent pause, as well as the number of chewing cycles during the sequence automatically. In order to estimate the distribution of chews over time in a sequence, each sequence was further divided into temporal quartiles, i.e., four equal sub-periods and the percentage of observed chews in each quartile was calculated, yielding a simplified frequency graph. Only sequences with eight or more chewing cycles were included in this analysis (approximately 89% of the whole sample, Fig. 3).

To describe the distribution of the behavioral measures over the course of a meal, each meal was divided temporally into thirds. Results are reported as means (SD) in Table 2 and Fig. 6. Due to the expected variation among individuals [19,22,38], box plots with 10–90% confidence intervals are reported in Fig. 4. The variability of the data obtained in the two tests was assessed using the intra-class correlation coefficient. ANOVA for repeated measurements, followed by post-hoc tests were used to analyze the change in behavioral measures over the course of a meal (Statistica 9.1).

3. Results

3.1. Video data validation

The frequency of chews derived from video recording and from magnetic recording of jaw displacement in women chewing gum did not differ significantly in any of the conditions studied [$F(2,15)=0.909$, $p>0.335$], the frequencies were significantly different among testing conditions [$F(2,15)=328.4$, $p<0.001$] and the frequencies derived from the two methods correlated strongly [$r(16)=0.996$, $p<0.0001$] (Fig. 2).

3.2. Meal analysis

While there was a considerable amount of inter-individual variation in all measures of eating behavior, the intra-individual variation was low as revealed by the intra-class correlation coefficients (Table 2). In an average meal, a woman took about 50 mouthfuls, most of which included between 8 and 20 chews (Table 2, Fig. 3).

The number of mouthfuls and, therefore, the number of chewing sequences changed over the course of the meal [$F(2,20)=3.67$, $p<0.05$], with a significant decrease during the middle of the meal [post-hoc: $p<0.03$], which was restored in the last third of the meal [$F(2,20)=5.32$, $p<0.02$, post-hoc: $p<0.02$] (Fig. 4 I).

The weight of the food in each mouthful decreased towards the end of the meal [$F(2,20)=6.57$, $p<0.007$, post-hoc: $p<0.002$] (Fig. 4 II).

The number of chews per sequence [$F(2,20)=0.32$, $p>0.7$], the frequency of chews [$F(2,20)=0.12$, $p>0.8$] and the duration of the sequences [$F(2,20)=1.03$, $p>0.3$] did not change significantly over the course of the meal (Fig. 4 III–V). However, the duration of the pauses between chewing sequences changed [$F(2,20)=4.29$, $p<0.03$], with a significant increase in the second third [post-hoc: $p<0.02$], which was restored in the last third of the meal [post-hoc: $p>0.24$] (Fig. 4 VI). Within the inter-mouthful interval the sequence/pause duration ratio was relatively constant during the meal [$F(2,20)=1.31$, $p>0.3$] (Fig. 4 VII).

The coefficients of the CIC derived from meals and corrected by the two researchers were strongly correlated (k-coefficient: $r(9)=0.995$,

Table 2
Characteristics of the cumulative intake of food (y) = $kx^2 + lx$, where x is the time, the k-coefficient is related to the change on the speed of eating over the meal and the l-coefficient is related to the initial speed of eating, duration of the meal and the number of mouthfuls and chews and chews/chewing sequence in 11 women tested twice. A sequence is an uninterrupted series of chews to manage a mouthful. The intra-class correlation coefficient expresses the repeatability of each measure across the two meals.

Characteristic	Mean (SD)	Intra-class correlation coefficient
Food intake (g)	264 (119)	0.87
k-coefficient	−0.15 (0.11)	0.83
l-coefficient	20.66 (4.13)	0.76
Meal duration (min)	11.4 (4.6)	0.75
Mouthfuls	51 (16)	0.85
Chews	794 (325)	0.88
Chews/chewing sequence	15.0 (11.8)	0.76

$p < 0.0001$ and l-coefficient: $r(9) = 0.982, p < 0.0001$, Fig. 5 I). The same coefficients derived by algorithmic correction of meals were also significantly correlated with the manually derived coefficients (k-coefficient: $r(9) = 0.965, p < 0.0001$ and l-coefficient: $r(9) = 0.945$, $p < 0.0001$, Fig. 5 II).

The overall pattern of chewing within sequences did not change significantly over the meal [$F(6, 90) = 0.58$, $p > 0.74$] (Fig. 6). However, the frequency of chews varied within the quartiles of the sequences [$F(6, 90) = 70.85$, $p < 0.001$]; significantly more chewing cycles occurred in the second and forth quartile compared to the first quartile [post-hoc: $p < 0.001$ in both cases] (Fig. 6).

It is noteworthy that the frequency of chewing a piece of chewing gum over 20 s was lower (0.96 (0.09) chews/s) than the frequency of chewing food over the approximately 8 s long chewing sequences (about 1.8 chews/s, Fig. 4 IV) and that while the chewing of chewing gum was constant, the frequency of chewing food varied over the quarters of the sequence (Fig. 6).

4. Discussion

The similarity between the CIC for ingestion of fluid in the rat and for ingestion of food in man (Fig. 1) encouraged us to develop a

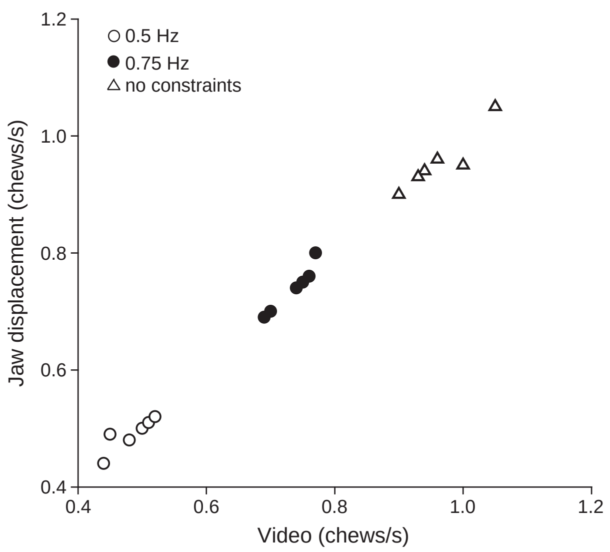

Fig. 2. Correlation between the frequency of chews derived from video recording of mandibular movements and chews derived from magnetic recording of jaw displacement in six women. Chews were measured during 20 s of chewing without constraints and metronome guided frequencies of 0.5 and 0.75 Hz.

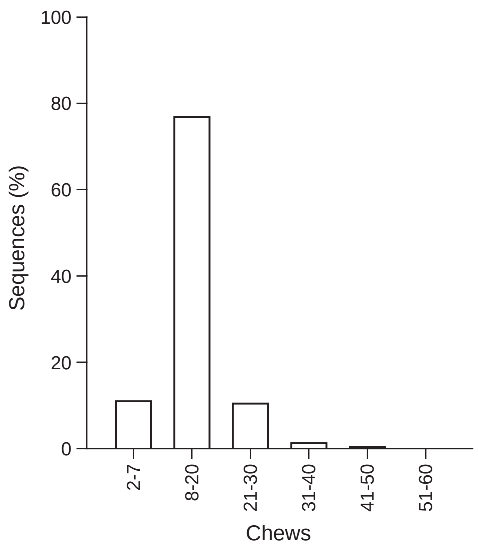

Fig. 3. Number of chews in sequences obtained from video recordings of the maxillary–mandibular regions of 11 women eating food from a plate placed on a scale.

method relating the pattern of chewing to the CIC throughout a meal in women. While the partial information on eating behavior which is derived from the CIC has already been used in clinical practise [37,39], we believe that the present method adds characteristics of the pattern of chewing that might guide the improvement of clinical practise for different patient groups. Previous methods have been limited by the use of liquid foods or "food units" rather than normal food [7,10,14,16,22,24] or the use of invasive equipment [25,26,48] and have reported average measures over the meal [43,44], with only limited efforts to relate the parameters of the CIC to the details of eating behavior [19,20,33,49]. The method developed here attempted to minimize these shortcomings.

Studies of model foods differing in hardness have validated video recording of the chewing cycle versus electromyographic recording [23]. We confirmed the validity of video recording by comparison with magnetic recording of jaw displacement [27] and found that both methods effectively registered an experimental decrease in chewing frequency. The strong correlation between the data collected with the two methods confirms the validity and sensitivity of video recording of chewing behavior.

By use of a video camera directed at the maxillary–mandibular region of the subject and another camera directed at the plate from which the subject ate and recording the weight-loss of the plate, data on the pattern of mouthfuls, chewing sequences and pauses between mouthfuls were combined with the weight of the ingested food, the cumulative intake of food and the duration of the meal. We developed a procedure that synchronized the data series and thus made automatic analysis of these details of eating behavior possible. Our past experience with meals recorded in a similar way [34,38], allowed us to identify the relatively few types of errors that occur when eating behavior is studied in this way and to correct them in a reliable way. The results obtained with this method confirmed the previous finding that eating behavior is inter-individually variable, but relatively stable intra-individually [34]. With access to high-resolution video cameras and motion capturing software, allowing detailed analysis and quantification of jaw movements [50] and perhaps analysis of chewing based on the generation of sound [28,29,51], the present method can be further simplified and automated.

By dividing the meal into mouthfuls, chewing sequences, pauses and the other details, the presented microstructural analysis may prove useful in exactly determining the behavioral elements that distinguish patients with eating disorders from normal individuals

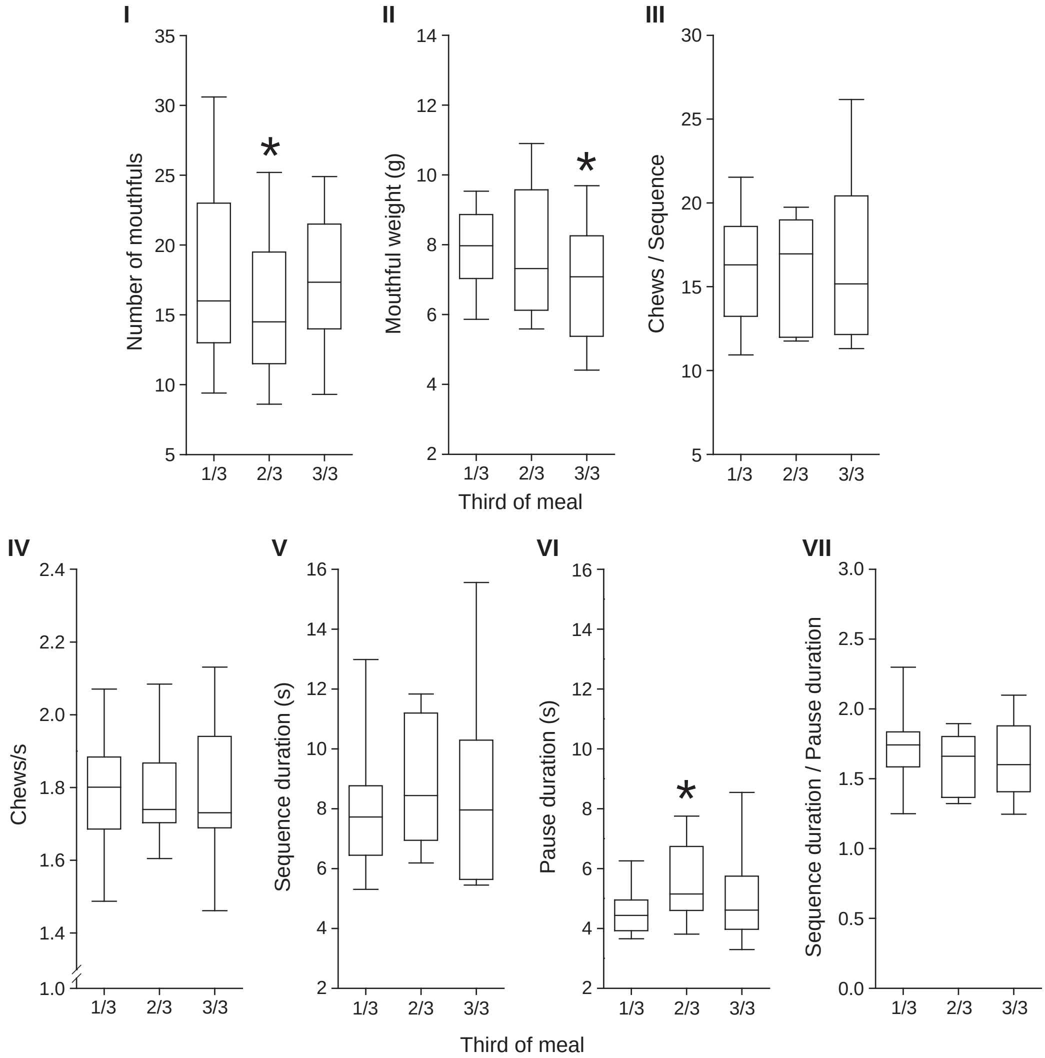

Fig. 4. Details of eating behavior obtained from recording the removal of food from a plate by a scale and from video recording of the maxillary–mandibular region of 11 women. Values are box plots during each third of the meal. *Significantly different from the value during the first 1/3 of the meal, $p<0.05$, post-hoc test after ANOVA.

and hence be useful in training the patients to regain normal eating behaviors.

In the present homogenous sample of healthy women, the number of mouthfuls decreased significantly in the middle third of the meal and, correlatively, the duration of the pause between bursts of chews increased. Both these measures were restored during the last third of the meal.

By contrast, the number of chews within sequences remained relatively constant, as did the ratio between duration of the sequence and the subsequent pause. The rate of chewing in women thus appears fairly constant, in accordance with previously reported results [15,16,24]. The average 1.8 chews/s found in this study is somewhat higher than the previously reported range of about 1.1 to 1.4 chews/s [15,16,19,20,24,33]. The differences can possibly be attributed to use of food items of predefined size, differences in the nature of the served food and to the fact that previous studies did not subtract the duration of the pause between one burst of chews and the next [15,16,19,20,24,33].

When, for descriptive purposes, we divided chewing sequences into quartiles, a stable pattern emerged with increased number of chews during the second and fourth quartile of each sequence. In animals, the characteristics and the difference stages of the chewing sequence have been described in detail [51–53]. While video recordings are impractical in differentiating among types of chews, our distributional results are in line with the previously described stages of the chewing sequence [54] and suggest that the human chewing pattern is relatively stereotyped, although the movements of the muscles used in producing this rhythm are variable [25,26,52]. However, it should be pointed out that different kinds of food can affect chewing [19,20,54–58]. Our finding that the pattern of chewing within sequences remains constant may therefore be applicable only to the conditions of our study.

While research suggests that chewing frequency is relatively stable, the frequency of chewing a piece of chewing gum was constant and much lower than that observed during chewing of food. These results indicate the importance of feedback derived from the food for chewing behavior both before [52,53,59,60] and during eating [19,20,54–58].

Individuals differ in the change of the speed of eating over the course of the meal, as measured by the k-coefficient in the CIC. Individuals with negative k-values are classified as decelerated eaters, whereas those who eat at a nearly constant rate, i.e., $k \approx 0$, are referred to as linear eaters [33,34,38]. Decelerated and linear eaters do not differ with regard to the other parameters of the CIC [33,34]. Interestingly, while the pattern of chewing remained relatively constant, the weight of the mouthfuls decreased during the last third of the meal. This finding

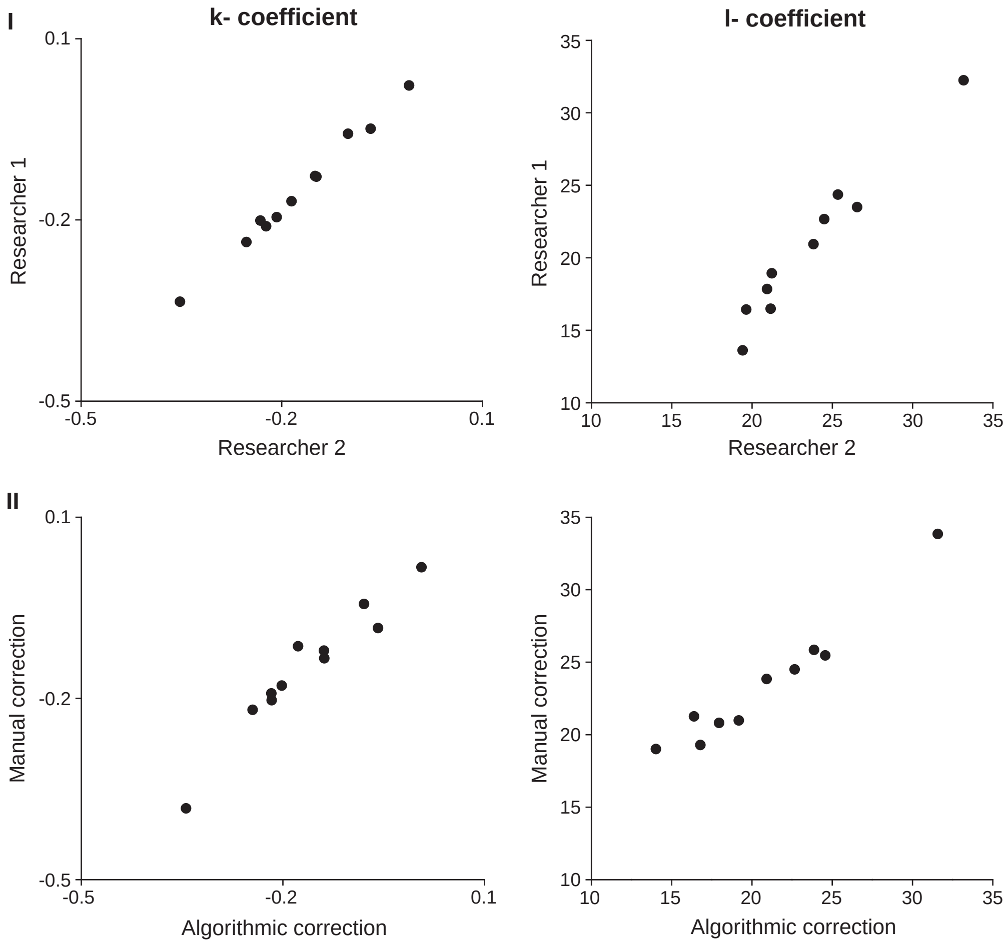

Fig. 5. Correlations between corrections of the k- and the l-coefficient derived from quadratic equations fitted on intake data series made manually by two external researchers (I) and manually and algorithmically (II).

suggests that a decrease in the amount of food ingested, rather than the pattern of chewing is related to the k-value of the CIC. The method presented here allows testing of this hypothesis and examining its importance for understanding the eating behavior of patients with eating disorders and obesity. Recent studies have suggested that compared with normal weight individuals, obese individuals take bigger bites, i.e., the equivalent to mouthful in the present study, at an increased [43] or at an unchanged [44] speed of eating. It will be interesting to compare the outcome using the present method with that of the methods used by others [43,44] in obese and normal weight populations in order to more precisely determine the eating behavior which possibly contributes to loss of control over body weight.

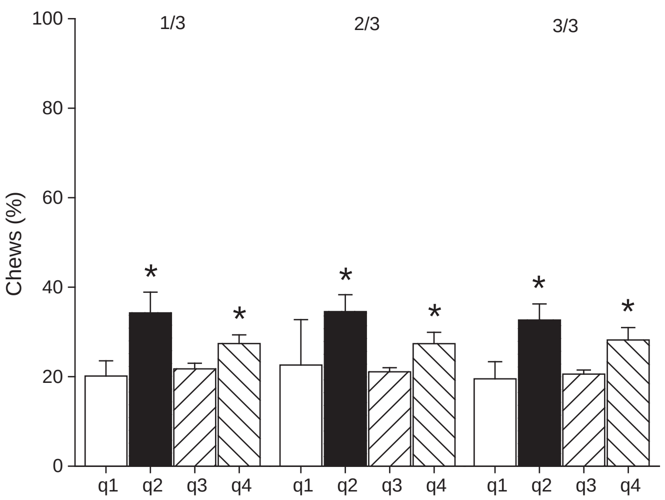

Fig. 6. Distribution of chews inside the chewing sequence over the thirds of a meal (1/3 to 3/3). Values are presented as percentages of occurrence of chews in each temporal quartile (q1 to q4, calculated separately for each burst, i.e. quartile duration = chewing sequence duration/4) of the chewing sequence. Values are means (SD) obtained from 11 women. *Significantly different from the first quartile, $p<0.05$, post-hoc test after ANOVA.

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Appendix A

Algorithm examples:

1.1. "Exclude utensil weight" filter

Let n the number of data points in the meal

Let w_i the weight in each data point

```
FOR i := 9 TO n − 8
  FOR j := i − 8 to i
    IF (( (w_{j+2} − w_j) EQUALS 34 ) OR ( (w_{j+1} − w_j) EQUALS 34 ))
      t_start := j + 1
  FOR j = t_start + 2 TO t_start + 16
    IF ( (w_j − w_{j−1}) EQUALS −34 ) OR ( (w_j − w_{j−2}) EQUALS
    −34 ))
      t_end := j − 1
  FOR j: = t_start + 1 TO t_end − 1
         W_j := W_i − 34
    IF ( (w_start − w_{start−1}) EQUALS −34)
      w_start := w_start − 34
    ELSE
      W_start := w_{start−1}
    IF ( (w_end − w_{end+1}) EQUALS 34)
      w_end := w_end − 34
    ELSE
      w_end := w_{end+1}
```

Note: This example refers to the knife weight exclusion. The filters for the "fork" and "fork & knife" weight exclusions are constructed similarly.

1.2. "Pressure before the mouthful" filter

Let n the number of mouthfuls time-stamped on the video feed
Let $t_m[1..n]$ a list of size n containing the time occurrences of the recorded mouthfuls
Let w a list of the weights in each data point

```
FOR i := 0 TO n
    w_max := HighestValueBetween( w[ t_m[i] − 4 ], w [ t_m[i] − 3 ],
    w[ t_m[i] − 2 ], w[ t_m[i] − 1 ] )
        IF ( ( w_max − w [ t_m[i] − 5 ] ) ≤ 6 )
                w[ t_m[i] − 4 ] := w[ t_m[i] − 5 ]
                w[ t_m[i] − 3 ] := w[ t_m[i] − 5 ]
                w[ t_m[i] − 2 ] := w[ t_m[i] − 5 ]
                w[ t_m[i] − 1 ] := w[ t_m[i] − 5 ]
```

1.3. "Pressure on the plate" noise filter

Let n the number of mouthfuls time-stamped on the video feed
Let $t_m[1..n]$ a list of size n containing the time occurrences of the recorded mouthfuls
Let w a list of the weights in each data point

```
FOR i := 0 TO n
  FOR j := 0 TO t_m[i + 1] − t_m[i]
        w_0 := w[ t_m[i] + j ]
        w_max := HighestValueBetween(w[ t_m[i] + j + 1 ],
                 w[ t_m[i] + j + 2 ], w[ t_m[i] + j + 3 ],
                 w[ t_m[i] + j + 4 ], w[ t_m[i] + j + 5 ],
                 w[ t_m[i] + j + 6 ])
        t_max := TimeOccurenceOf (w_max)
    IF ( (w_max > w_0) AND (w_max − w_0 < 4) )
      FOR k := t_max TO t_max + 6
        w_1 := w[k]
        IF( w_1 EQUALS w_0 )
              FOR l := t_max TO k
                      w[l] := w_0
```

Note: The "pressure on the table" filter is similar, with minimum instead of maximum value calculation.

1.4. "Memory buffer" filter

Let n the number of mouthfuls time-stamped on the video feed
Let $t_m[1..n]$ a list of size n containing the time occurrences of the recorded mouthfuls
Let w a list of the weights in each data point

```
FOR i := 0 TO n
  IF ( (w[t_m[i]] − w[t_m[i] + 1]) ≥ 0 )
          MouthfullRecorded = false
  ELSE
          MouthfullRecorded = true
  IF (MouthfullRecorded EQUALS false)
          FOR j := t_m[i] + 1 TO t_m[i] + 4
                IF ( ( w[j] − w[j + 1] ) ≥ 5 )
                      w[t_m[i] + 1] := w[j + 1]
                      t_down := j
          FOR j := t_m[i] + 2 TO t_down
                w[j] := w[j] − (w[ t_m[i]] − W[ t_m[i + 1]])
```

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