Case study: Use of surface electromyography in masseter to investigate the muscular effort and movement features during the naturally chewing and swallowing

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Abstract*— Chewing and swallowing patterns was large described as a risk factor for degenerative diseases diagnosis. In this paper, the electromyography technique was used to collect the electrical potential from masseter muscle. Aiming to extract the movement features and muscular effort during chewing activity of a solid aliment - gummy. Was used an accelerometer - detecting the hand movement - to facilitate the visual segmentation of each mastigation and swallow signal. The maximum voluntary contraction was obtained by the forced chew in an Parafilm positioned between the molar teeths. The signal characteristics was obtained through those data analysis methods: Root Mean Square (RMS), Teager–Kaiser energy operator (TKEO) and double threshold. The protocol proceed was made with one health subject, adult, male, instructed to naturally chew the aliment. The results shows significant differences on the RMS value ($p < 0.01$) between the first chewing stages and the final one (25, 50 and 75%). In conclusion, as shown in results, the electromyography can be used to detect the chewing pattern and stages - initial (bite) and final (swallow).

***Keywords*— masticatory; masseter - muscle; movements.**

I. INTRODUCTION

In the modern society the life expectancy is progressively increasing. At the same time, some neurodegenerative diseases linked to the age, are appearing. Disorders and disturbs can be identified from several biological signals, one of these is the masticatory pattern.

A neurodegenerative disease (ND) is an illness that has progressive and adverse effect on the function or structure of the neurons of the brain. In the Predict ND context, we define ND as a class of progressive illnesses which affect cognitive functions such as learning and memory ultimately causing dementia. Examples of these illnesses are the Alzheimer's Disease, vascular dementia, fronto-temporal dementia, Lewy-Body dementia, and Parkinson disease **[1].** NDs are a major challenge, since dementia alone accounts for costs equivalent to about 1% of the global gross domestic product (GDP) - 461 billion euros annually.

There were 36 million people living with dementia worldwide in 2010 but the number is expected to increase to 115 million by 2050 **[2].** The diagnosis of these diseases are not easy and healthcare costs related to diseases are projected to rise dramatically in the near future **[3].** Accurate diagnosis increases the chance of effective treatment and reduced disability over time, which reduces direct and indirect healthcare costs **[3].** These pathologies are progressive degenerative processes that are becoming more serious over the years and have a major impact on professional, social and family of patients, leading to a total inability to exercise any type of everyday activity.

A several of central nervous and pheripheric disfunctions, affect chewing moviments and swallowing. A recently study presetend there was statistically significant difference on chewing pattern between individuals with Parkinson's disease and without the disease. Analyzing the temporal and masseter muscles in non habitual mastication of Parafilm M®, and normally chewing of Peanuts and rises. The results suggest that Parkinson's disease interferes in the electromyographic activity of the masticatory cycles by reducing muscular efficiency **[4].**

Weak masticatory muscles tire easily, so that food is chewed with difficulty, while bulbar muscle involvement leads to problems with phonation, articulation, and swallowing **[5].** Mastication is correlated with health in general as well as with digestive processes and peripheral sensory and motor input to the brain likely rendering physiological benefits to central nervous system cognitive areas. Taken together, the data suggest that mastication plays a role in cognitive functions and its impairment may constitute a risk factor for dementia and chronic neurodegenerative diseases associated with aging **[6]**.

In this way, monitoring dietary behavior is a prerequisite for effective diagnosis, prevention, and intervention. **[7]** During mastication, the size, texture, and moisture of the food gradually change. Masticatory muscle activity patterns adapt to these changing characteristics during the process of bolus formation. **[8]** Different foodstuffs show various changes in the oral cavity during mastication. **[9,10]** On the other hand, humans can modify their habitual masticatory patterns to adjust to the physical properties of food.**[11, 12, 10, 13]**

Temporomandibular joint movement during mastication with possible loading and unloading of joint structures is subject matter of many hypothetical models; yet, many questions remain unanswered. In one of the initiator studies of the functional pathways of the condyle, it has been shown, that opening and closing trajectories of the temporomandibular joint are not identical during chewing [14]. Most studies have been able to describe electromyography as a method to extract features from the movement of the muscles used during food ingest.

Electromyography (sEMG) is a technique for monitoring the electrical activity of excitable membranes, representing the measure of the action potencies of the sarcolemma, as a voltage effect as a function of time. The electromyographic signal is the algebraic summation of all the signals detected in a certain area, and can be affected by muscular, anatomic and physiological properties, as well as by the control of the peripheral nervous system and the instrumentation used to acquire the signals [15] The sEMG record, obtained with surface electrodes allows to analysis the signal in the time and frequency domain. In other words, what proportion the number of motor units activated increases during a muscular request and how many times the motor units are activated in an isometric or dynamic condition.

EMG has many applications; for instance it is clinically for the diagnosis of neurological and neuromuscular problems. Laboratory research applications are biomechanics, motor control, neuromuscular physiology, movement disorders, postural control and physical therapy (Kale and Dudul, 2009). **[16]**

Electromyographic recording is the primary technique used to monitor these physiological processes, and its results have shown a clear relationship between muscular activity and food characteristics **[17,18].** Moreover, the proprioceptive information obtained from muscle activity, as recorded by sEMG, may serve as the sensory basis for food texture perception **[18,19].**

Human mastication is a complex biomechanical process. Many different structures, tissues and functional units are involved. The great variability observable in the procedures of crushing and lubricating food constrains the clear distinction between physiologic and pathophysiologic chewing pattern. Diagnostic procedures on masticatory performance are still lacking clear definitions and classifications. The use of individual chewing performance data in restorative dental procedures is not yet established. **[20]**

The present study was designed to investigate whether the masseter muscle signal characteristics changes along the masticatory process. The hypothesis is that the RMS feature from the sEMG signal (which is related to the muscular contraction) decreases along the chewing process, as the effort do it gets smaller as the food is comminuted. As well as the stage of masticatory cycle which reflects a better signal quality, comparing the signal patterns in the inicial chewing with the last chewing. And to evaluate the accuracy of each result.

Was used the surface electromyography technique with one muscle during the normally chewing of one solid aliment: gummy. The data analysis presented how the signal features changing with food reduction in the time and frequency domain.

II. MATERIAL AND METHODS

A. Instrumentation and sEMG Data Acquisition

The experiments performed were approved by the Ethics Committee with Certificate of Presentation for Ethical Appreciation CAAE 89638918.0.0000.5547, 2.759.577. The Data collect was performed with the sEMG acquisition system EMG System do Brasil, which have four channels. Two channels was used to measure EMG signals from **masseter** and other to measure inertial data from the hand movements.

Subsequently, the characteristics and classification of the patterns was extracted by filtering, segmentation and statistical analysis of the signals through the software MatLab version R2012a.

B. Experimental procedure

An Ag-AgCL, bipolar, surface electrodes were adhered to the skin, constituting a detection surface that captures the current through the skin-electrode interface. The electrodes were associated with a conductive gel (electrolyte).**[21]** The skin was cleaned with alcohol seventy percent. The electrodes were positioned perpendicularly to the muscle fibers and between the motor point and the muscle insertion tendon. The reference electrode was positioned above the posterior auricular, who is located behind the ear.

The data was collected from one health subject, male. Was fixed one free time window cycle for natural chewing of the gummy and other to maximum voluntary contraction of masseter using the Parafilm located on molar teeth. The subject was instructed to chewing normally. An accelerometer, fixed on right hand, was used to synchronize the exactly initial and final point of the masticatory movement. This is useful to the signal visual segmentation.

The protocol consisted of to begin with the forearm above the thigh, forming ninety degrees in relation to the trunk. And with a verbal command, the subject started the movement of to carrier the food to the mouth. After to swallow the food this proceed described is repeated.

This facilities the posterior analysis of the signal and to correlate the features extracted with the moment showed in the generated graphics.

C. Signal processing

First the signal was **normalized**, as a method for facilitating the reading and data analysis by dividing the values obtained by a reference value. In this case, the maximum voluntary contraction (MVC).

The signal was **normalized** from **-1 to 1** scale, dividing each sEMG datum by the **99th percentile** of the absolute value of the MVC. Then also was calculated the **root mean square** (RMS) in voltage of muscle activity signal. This measure actually has a functional meaning that is originally associated with calculating the power (P) delivered to the system by an electromotive force (E). [22] In this type of analysis is possible use the values in **RMS**, the integral and the value rectified by the average frequency, which gives parameters of the signal amplitude. [23]

The RMS for a collection of N values {x1, x2, ..., xN} is given by the formula:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \qquad (1)$$

Already the **filters** serve to attenuate undesirable signals. At sEMG, when the frequency of the noise differs from the frequency of the signal of interest, its use makes it possible to clean the signal.

Signals were analog band-pass filtered at 10–500 Hz, using a fourth order **Butterworth** digital filter. To remove power line undesired frequencies, a **Notch IIR** filter with a quality factor Q=100 at 60 Hz was applied on the signal (all harmonics until the ninth harmonic was also filtered).

Firstly, a Teager–Kaiser energy operator (TKEO) is used to rectification and onset detection. In order to segment the signal (select the windows of interest which contains signals relative to masticatory events) a ***<u>threshold-based method</u>*** was applied to signal.

The non-linear TKEO, introduced by Kaiser (Kaiser 1990; Kaiser 1993), measures instantaneous energy changes of signals composed of a single time-varying frequency. One advantage of TKEO output, compared with other onset detection methods, is that the calculated energy is derived from instantaneous amplitude and instantaneous frequency of the signal.

The discrete TKEO ψ was defined as:

$$\psi[x(n)] = x^{2(n)} - x(n+1)x(n-1) \qquad (2)$$

Where x is the EMG value and n is the sample number. TKEO was always applied after the signal was band-pass filtered. [16]

Posteriorly, was applied a low-pass filtering at 50 Hz, 2nd order Butterworth, detected through a double threshold - based on mean and standard deviation from signal noise.

The **double threshold** is a method used to determine the onset or termination (or ~~both~~) of an sEMG burst in which both amplitude and time criteria are applied.

The threshold T was determined as:

$$T = \mu + h\sigma \qquad (3)$$

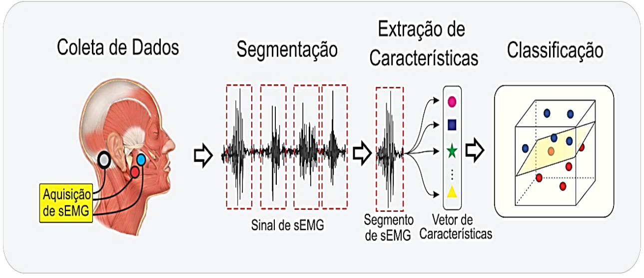
Where h is a preset variable, defining level of the threshold.

All parameters of the TH algorithm were set to maximize the t1 accuracy, and were based on recommendations by Hodges and Bui (1996). After **TKEO** processing, threshold was set at h = 15 due to very low magnitude of the baseline. [16]

The **double threshold** method is the most rigorously tested and validated computer algorithm (DiFabio 1987; Hodges and Bui 1996; Micera et al. 2001). It involves calculating the mean and standard deviation of baseline EMG activity in the absence of any muscle contraction. The **first threshold** criterion is that EMG amplitude must surpass a value that represents the 95% confidence interval (μ ±1.96¬) for baseline activity. The confidence interval may be extended to 99% (μ ± 2.58¬) or greater if the level of baseline activity is significant.

The onset point and waveform are both plotted on the computer screen. The band-passed sEMG is superimposed for the operator to verify the point obtained by the double threshold criteria. Misidentified onsets can then be corrected using a cursor to digitize the visually inspected data point. [22] Al the process steps includes, in synthesis: filter, highlight, rectify, smooth, segment, extract features, and analyze.

Figure 1: sEMG signal processing flowchart:



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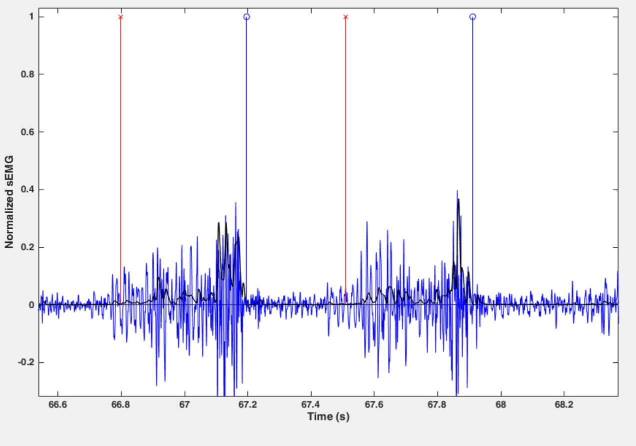
III. RESULTS AND DISCUSSION

As would be expeced, during forceful centric occlusion the masseter muscle is very active (Pruzansky, 1952; Moyers, 1950; Ahlgren, 1967; Vitti and Basmajian, 1975, 1977) [21]. Results support the hypothesis that sEMG signal, and thus muscle effort, vary throughout chewing. During chewing movements the maximal activity occurs in the masseter at about the time the jaw reaches the temporary position of centric occlusion wich acconts for about a fifth of the chewing cycle (Gibbs, 1975). [21].

The static analisys accuracy shows significant differences between the RMS value ($p < 0.01$) between the first chewing stages and the final one (25, 50 and 75%).

As well as the signal characteristics comparing chewing process with swallowing.

Figure 2: Electromyography signal of chewing cycles.



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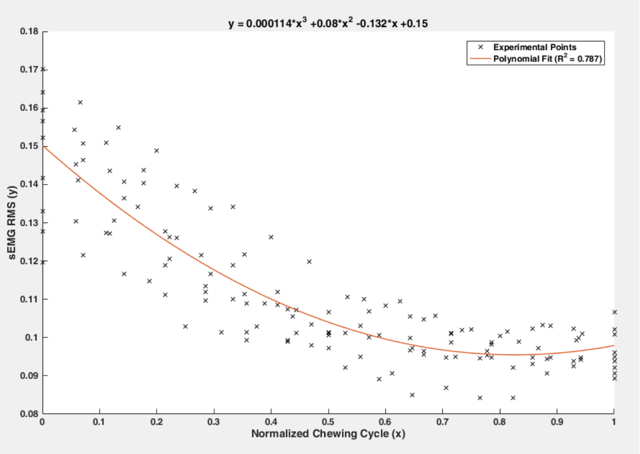
The start and end points was visually determined correlating the accelerometer signal with the chew and swallowing moments: The subject would raise and lower his hand when the food was swallowed, and the accelerometer also detected the moviment of to carrier the food to mouth. Totaling the nine repetitions of the experimental protocol.

The black line in the graph represents the normalized, filtered, rectified signal, as well as with the Teager–Kaiser applied. The threshold define the signal range corresponding to electromyography.

The lowest signal corresponds to the opening of the mouth, and the highest signal demonstrates the occlusion movement. The segments perpendicular to the signal refer to the inicials and end points of each chewing movement. The cycles were normalized between 0 and 1. 0 is mouth opening and 1 is swallowing.

Figure 3: Features extracted.



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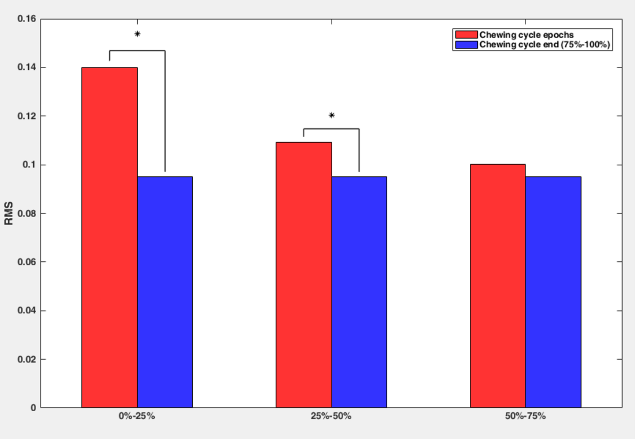
From original signal and the signal with processing was calculated the RMS in each chew. Then a third degree polynomial adjustment was made generating the polynomial adjustment function and the experimental points. This image illustrates the features extracted with the correlation factor. Note that a trend has been found. The electromyographic data do not have normal distribution, so the Wilcoxon test was applied for a $p < 0.01$. The asterisks in the figure show where the difference was significant.

Figure 4: Stages of the masticatory cycle..



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IV. CONCLUSIONS AND FUTURE WORK

Thus, it has been demonstrated that this technique can be used to identify the stages – initial (bite) and final (swallow) – of a mastication cycle and too the required effort to ingest determinate aliments.

Because it is a practical, inexpensive and noninvasive technique, it can be used to assess the recovery of patients with neuromuscular dysfunction. For example, in electromyographic biofeedback applied in physiotherapy rehabilitation sessions, where muscle strength could be correlated with sEMG signal characteristics and intensitys. Enabling more palpable results during rehabilitation. In other words, it was estimated if due to a given intervention, there would be greater recruitment of the motor units - muscular force increase - physiological improvement.

Another application concerns man-machine interface devices, such as controlling prosthetics and orthoses and creating a cerscent range of rehabilitation-oriented electronic games. As well as communication with various electronic devices, such as personal computers, mobile phones and tablets or any other vehicle for facilitating human activities.

In the future, the experiment will be replicated in a larger sample of individuals. Also the physioelectric characteristics of the infrahyoid and temporalis muscles will be analyzed using the same parameters for data treatment. Other foods with distinct textures will be explored. Lastly, a database of sEMG of the masticatory and swallowing muscles will be created.

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