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TECHNICAL PAPER

Automation of the process for accessing lip forces

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Abstract The decrease of lip strength results in the absence of lip contact, which may result in musculature neuromuscular imbalance and affect several functions, such as harmonic dental growth, swallowing, speech and breathing. The measurement of lip strength is an important task in clinical speech pathology practice. This paper describes the development of a measurement system to be used in the processes of force assessment of lips. The user can follow the measurement by means of an interface, which allows registration of information, such as patient personal data, measurement and a brief report. The developed system may be used on personal computer at Windows® platform.

Keywords Automation · Automatic measurement systems · Automation interface · Lips force

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1 Introduction

Reduced lip force can lead to lack of lip contact, which is a possible cause for neuromuscular imbalance, affecting functions such as harmonic tooth growth, swallowing, fonation and breathing [7, 16]. Evaluation of lip force is thus part of routine speech pathology clinic, serving as an indicator of the need for specific therapy as well as to access the success of a given rehabilitation approach [10].

Current practice involves subjective evaluation, as shown in Fig. 1. In a clinical evaluation procedure, the patient is asked to produce reaction forces against the gloved finger of the therapist resting in the outer tooth surface, alternating the upper and lower lip. Based on the sensory impression, the therapist classifies the lips as normal lip pressure, below normal or lip pressure above normal. One of the difficulties in this evaluation is that it does not allow for an evaluation of the upper and lower lips acting together. Another problem is the high dependence on the person in charge of the evaluation process. Several factors affect the results of the evaluation, such as clinical experience of the professional and finger position [6].

Different approaches are described in the literature, none of them entirely consistent with the previously described current clinical practice. Surface electromyography has been used as a complementary tool for evaluation, currently the only available exam to complement the clinical subjective assessment.

The idea behind electromyography is to take into account the electrical potential generated by the muscular activity, which is measured and used to correlate to muscle

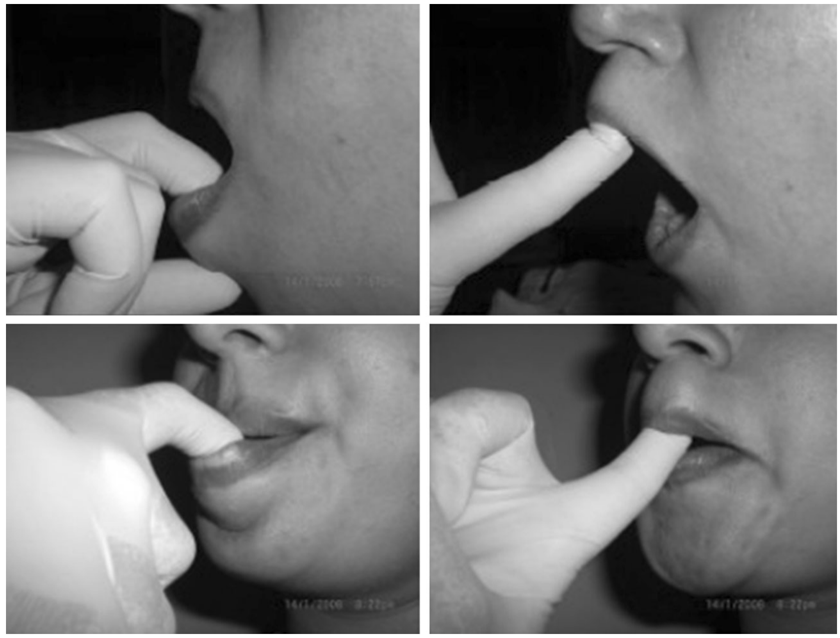

Fig. 1 Subjective lip force evaluation

force and function. Different studies relate the muscular force and function to the measured muscular electrical potential for perioral muscles [2, 13, 16].

Besides determining the real force, it is also important to follow improvements obtained during treatment [4, 5]. With the possibility of measuring precisely the force, it is possible to determine the effectiveness of a given treatment, the evolution of the patient in time and also to exchange data with professionals from other areas, such as orthodontics, physiotherapists and medical doctors.

Within this context, it is valid to assume that collecting quantitative data by means of an objective method to measure lip forces under clinical supervision may consist in an important auxiliary device to the diagnosis and prescription of appropriate therapy, and also to facilitate communication between the clinical group and the patient.

For the proposition of a solution to the problem of measuring lip forces, concepts of Engineering Biomechanics are used, combining Mechanical Engineering to Biology and Physiology for the design, modeling, development and analysis of devices and systems in Biology and Health Sciences [15].

This paper aims at describing a new system of lip force measurement in humans, with the additional feature of providing an evaluation of the lips. The measurement system uses a functional principle similar to a method used in Speech Pathology clinical practice, and provides quantitative measures of individual lip force. The project was approved by the Bioethics Committee of the Federal University of Minas Gerais under number 525/06.

1.1 Description of the adopted measurement technique

The measurement method uses a sensor element positioned between the lips mechanically coupled to a force transducer (Fig. 2). The transducer generates a signal to the data acquisition device, connected to the computer. The system is then processed and stored.

1.2 Sensor

For the correct design of the sensor, it was necessary to consider physiological and anatomic information on the muscles to be evaluated, the perioral muscles, including a field work to define the proper dimensions for manufacturing the device, which should be positioned between the lips.

The shape and position of the insert were established based on the descriptions of the related muscles in the literature. At one side of the insert is the elliptic mouth perioral muscle, which follows the mouth line [12]. At the other side are the two dental arcades, upper and lower that in individuals without dental or orthodontic alterations have the shape of two parabolas. Besides defining the shape, a study was performed to define average measures of the muscles.

Inter-corner distances of 100 individuals were measured (50 samples for each gender). Individuals between 18 and 40 years old (average 23.72 years) without visible alterations in orofacial structures. The measurements were performed with the individuals sitting and with closed lips, using a pachymeter. The obtained average values were 51.28 ± 3.42 mm for women and 53.92 ± 3.47 mm for men.

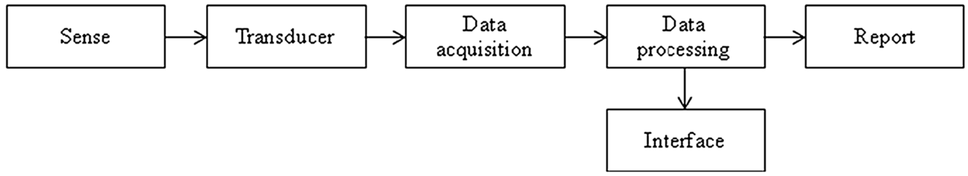

Fig. 2 Functional diagram of the force measuring system

Fig. 3 Inter-corner sensor element used in the evaluation

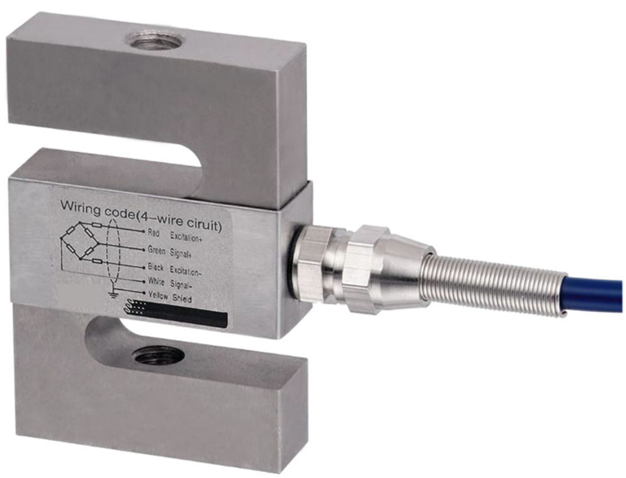

Fig. 4 Load cell

The measurements indicated that there is no significant interpersonal variation of distance between the corners of the mouth. To facilitate the manufacturing process, the value of 50 mm was used as reference distance between mouth corners. Considering the position of the muscle in relation to the mouth corners, 10 mm was added resulting in the dimension of 60 mm for the fabrication of the insert length (lateral–lateral). It should be noted that the force measurements described in this work were all made in women.

The final design of the insert, shown in Fig. 3, includes an elliptic shape with double parabolic curvature and 60 mm total length. The manufacture process was rapid prototyping, using an nontoxic polymer approved for biologic safety for human use.

The inter-corner sensor should be placed between the frontal teeth and the lips of the patient. The sensor, which corresponds to the gloved finger of the professional in traditional clinical evaluation, is coupled mechanically to a force transducer.

1.3 Force transducers

As in the clinical practice subjective lip force evaluation, the patient is asked to press the lips against the sensor, previously slightly displaced from the rest condition, generating a counter resistive force. This force is transmitted to the force transducer, a load cell, by a mechanical coupling (Fig. 4). It is used as a load cell of type S, consisting of a Wheatstone bridge. This load cell generates an analogical tension signal when displaced.

The sensitivity of the load cell is 2 mv/V, calibrated within narrow tolerance range (±0.1 %). It does not require further adjustments and guaranteeing interchangeability without additional calibration and has the capacity for 5 kgf and a combined error smaller than 0.05 % of nominal output.

The signal provided by the load cell is processed and stored in digital media.

1.4 Signal processing

The signal transferring, storing and processing system is composed of a 16 bits ONTRAK data acquisition device (DAQ), model ADU100 series B02086 [14], with an USB port, an electronic coupling and a personal computer.

The measuring system interacts with the user by means of a supervision man–machine interface. The man–

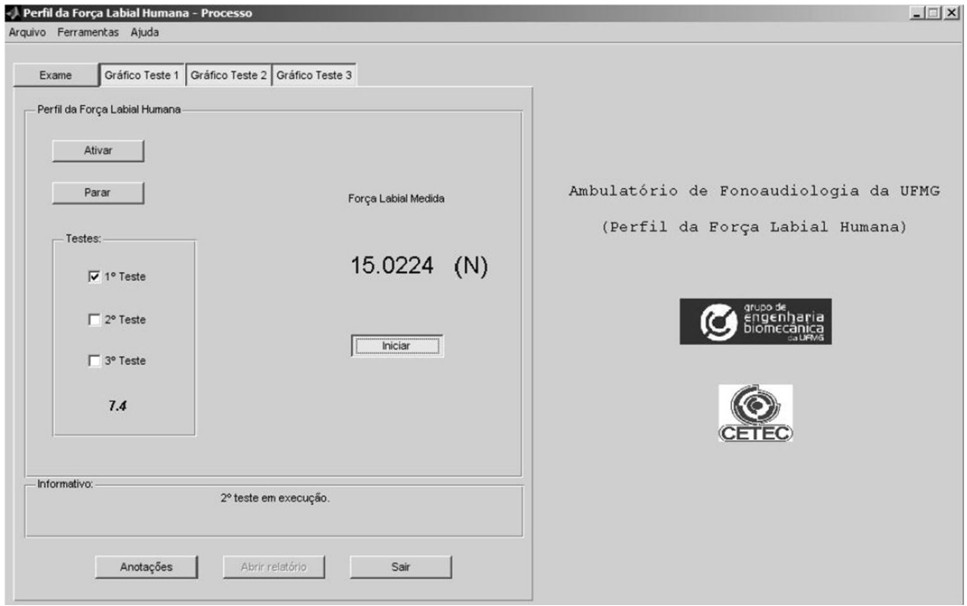

Fig. 5 Man–machine interface system

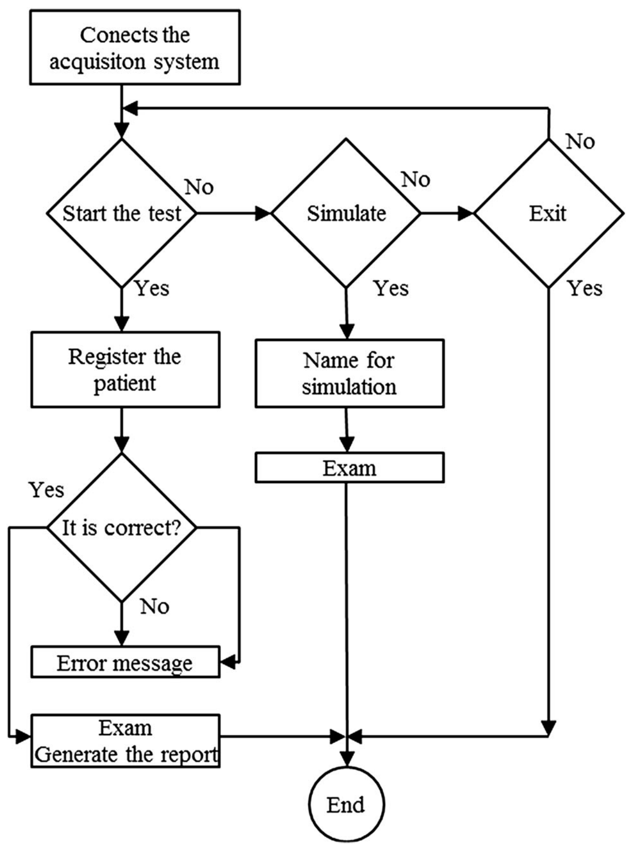

Fig. 6 Functional flowchart of the software

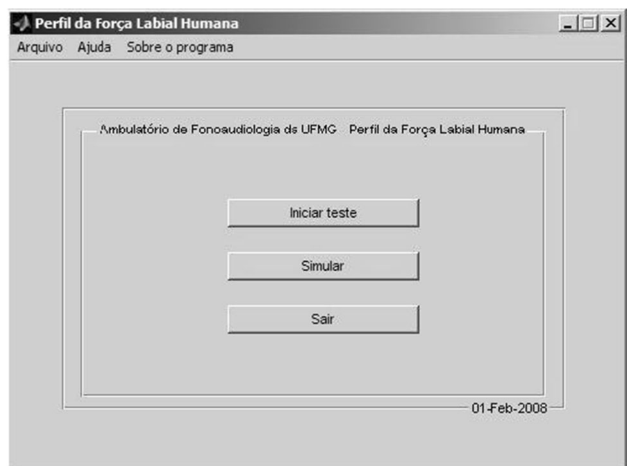

Fig. 7 Initial windows for the software

machine system, shown in Fig. 5, was developed using MATLAB® 2007b, programmed in visual GUIDE [8, 9] and has low-level control using (Dynamic-link library), provided by the DAQ manufacturer. The system runs in Windows® operating system.

The program allows the user to store information related to the evaluation process, such as date of the exam, birthday, time of the exam, result of the subjective evaluation, as well as other information the user might consider to be relevant.

It allows a follow-up of each of the three repetitions of measurement, observing the maximum force levels after a predefined period of time. The patient is warned by a sound signal generated by the program of the time to start and finish the test. The user can modify the execution time and number of tests that he/she plans to apply to a patient.

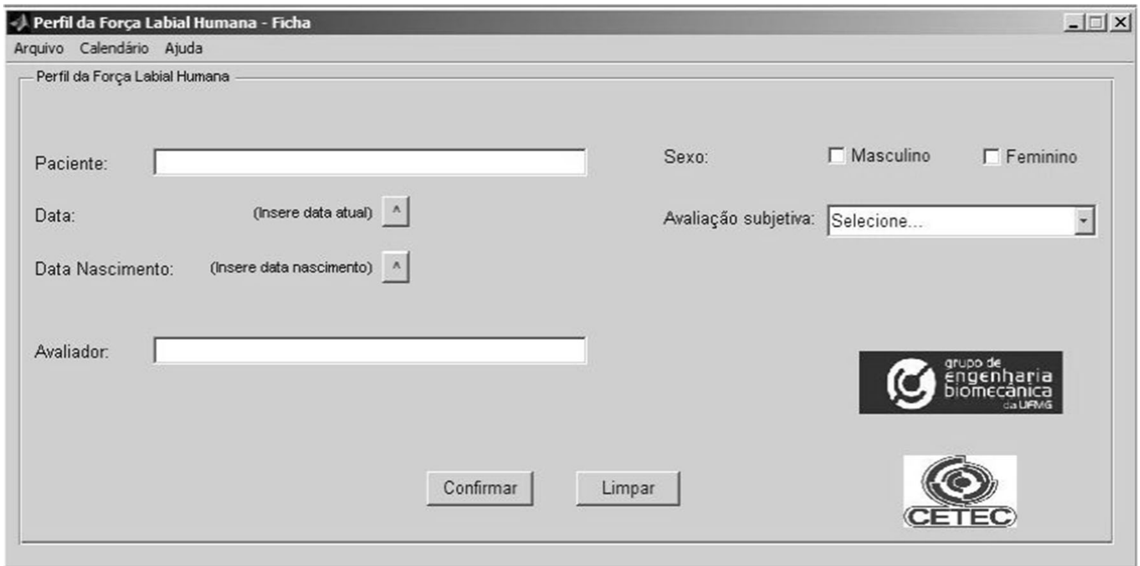

Fig. 8 Patient registration sheet

After three repetitions of the test, a report is issued with the profile of force of the patient. In the first page of the report, the time versus force curves (profiles) of the three tests are shown separately and values of maximum, minimum and average forces during the test are given in the second page. A spread sheet with the force values at each 1/100 of a second is also produced for the user.

1.4.1 Algorithm

Figure 6 shows the functional flowchart for the software. The data acquisition system should be connected to the computer and the program started.

The program starts providing three options to the user: to start the test, to simulate or to exit the program, as shown in Fig. 7. By choosing to start the test, the user is asked to register the patient (Fig. 8) and then to perform the test. After the exam, a report is issued with the provided patient data and the measurements obtained in the test.

By choosing the simulation option, the user runs the test routine just for training purposes. The algorithm ends after the generation of a report, or when the user decides.

1.5 Exam

The exam starts with the patient in the sitting position, when he/she is asked to fit the insert between the lips. A period of 60 s is then waited after the correct fit of the insert for accommodation. The participant should be as comfortable as possible.

After the accommodation period, a small displacement is imposed by the professional to the insert in the outwards direction, and the user is asked to exert an inward force against it, maintaining it for 10 s. Following a 2-min rest period, a new measurement is performed. The procedure is repeated one more time, with a total of three measurements for each patient. The duration of each test is controlled by the software.

The three measurement sets are used to define the lip force profile for the patient. Characteristic points such as average force, maximum force and fluctuations can be identified, besides the force $\times$ time curve representing the profile.

1.6 Measurements

The measurements were performed in two different steps. First, a subjective lip force was performed by trained professionals. Then, the proposed device was used for quantitative measurement.

The subjective evaluations were done independently by three Speech Pathologists, specialists in Oral Motility, using the same procedures. They classified the force levels as normotensive, slightly hypotensive or hypotensive. The evaluation consisted in palpation of the lips in rest, palpation of protruded lips and counter-resistance force evaluation. The professionals used disposable gloves and the instructions given to the patients were to maintain the normal lip posture and then press them against the finger of the evaluator, using maximum force. Separate evaluations were done for upper and lower lips.

Only individuals with lips classified as normotensive by all three evaluators were included in the research group. Those reporting any disorder in the oral sensory system, as

Fig. 9 Head support (*left*) and patient using the head support (*right*)

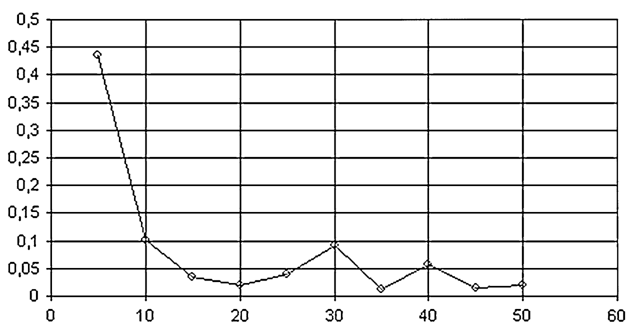

Fig. 10 Uncertainty measurement system (*y*-axis) by force, N (*x*-axis)

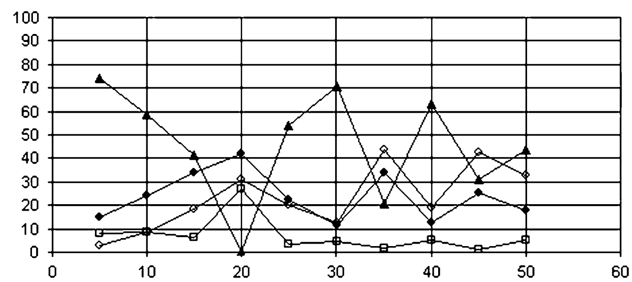

Fig. 11 Relative values of the uncertainty (*y*-axis) and force, N (*x*-axis). *Circle* (standard), *circle bold* (resolution), *triangle* (reproducibility) and *square* (interpolation)

well as patients with unusual lip frenulum or dental structure (orthodontic pathologies such as open bite, cross bite, dental alignment, or orthopedic problems such as nonstandard mandible–maxilla proportion) were also eliminated.

The sample consisted of 20 women, aged between 20 and 28 years old (average 23.2). As the purpose of the study was not clinical, but to examine the effectiveness of the proposed device, a homogeneous group has used, to access the range of variation of the measures.

After the first measurements, a tendency of the patients to react to the instruction of pressing the lips by moving their heads was observed. The produced force was then the sum of the lip force and the cervical additional component. A head support has been designed and constructed aiming at providing a rigid support for the head during the tests. The support is shown in Fig. 9. It allows the adjustment of height and head perimeter, making it possible to eliminate the vertical component of the force by leveling the steel wire. It can be easily transported, and avoided the back and forth movement of the head and the corresponding cervical forces.

For the tests, the patients were asked to sit in a chair, after that the head support was fixed and adjusted. The insert was then positioned behind the lips. The insert was then moved to the test position, 1 cm displacement away from the frontal teeth, so as to isolate it and allow the lip action. With the insert at the test position, the steel wire is extended, allowing the correct transfer of the lip force to the load cell.

Fig. 12 Patient doing the exam

1.7 Calibration

Calibration is the validation of specific measurement techniques and equipment. It is the act of checking or adjusting (by comparison with a standard) the accuracy of a measuring instrument [1].

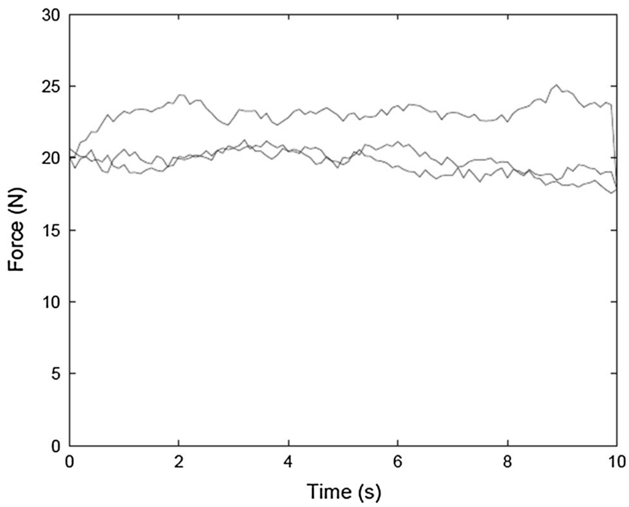

Fig. 13 Lip force profiles (raw data)

The measurement system was calibrated at the Laboratory Isaac Newton of CETEC, which is certified by the Brazilian metrology agency INMETRO to measure the quantities force, mass and torque. The measurement system consisted of the force transducer, the data acquisition board and personal computer and was calibrated in the way of traction according to the ASTM [3] and ABNT [1]. The polynomials generated are represented by Eqs. (1) and (2), where R is given in millivolts and the force F in Newtons. The parameters are: $a = -7.9656 \times 10^{-2}$, $b = 2.1268 \times 10^{-1}$, $c = -5.6818 \times 10^{-8}$, $a' = 3.7454 \times 10^{-1}$, $b' = 4.7019$ and $c' = 5.9812 \times 10^{-6}$.

$$R = aF^0 + bF^1 + cF^2 \quad (1)$$

$$F = a'R^0 + b'R^1 + c'R^2 \quad (2)$$

The whole measurement system was calibrated steady state through standard primary force and showed a maximum uncertainty of ±0.43 % of the measured signal, as Fig. 10.

The degree of the polynomial shown as characteristic curve is defined by the standard technique used in the calibration [3]. Figure 11 shows the relative values of the components of uncertainty, and analyzed the resolution of the measurement system, the interpolation and reproducibility, which is the degree of agreement between the results of measurements of the same measured carried out under different conditions of measurement [11].

Table 1 Measures of central tendency and dispersion of the averages three tests on each subject

Participants	Age (years)	Test 1 (N)	Test 2 (N)	Test 3 (N)	Average (N)	Standard deviation (σ)	CVP (%)
1	20	11.17	7.06	9.29	9.17	2.06	22.43
2	26	13.19	14.36	14.69	14.08	0.79	5.60
3	22	7.53	7.22	8.97	7.91	0.93	11.81
4	25	4.43	7.20	7.07	6.23	1.56	25.08
5	21	9.93	5.04	6.21	7.06	2.55	36.17
6	28	6.96	7.67	7.35	7.33	0.36	4.85
7	24	12.49	10.58	11.70	11.59	0.96	8.28
8	23	9.56	11.96	6.74	9.42	2.61	27.24
9	22	5.85	8.66	7.09	7.20	1.41	19.56
10	24	10.25	10.86	9.84	10.32	0.51	4.98
11	23	9.06	8.20	9.51	8.92	0.67	7.46
12	20	3.99	8.61	7.96	6.85	2.50	36.49
13	22	8.33	10.22	7.44	8.66	1.42	16.39
14	23	4.76	7.47	8.35	6.86	1.87	27.28
15	23	10.58	12.59	20.08	14.42	5.01	34.73
16	21	5.14	9.91	6.98	7.34	2.41	32.76
17	25	5.85	10.76	10.72	9.11	2.82	30.99
18	23	7.54	8.18	7.52	7.75	0.38	4.85
19	27	12.21	11.01	8.83	10.68	1.71	16.04
20	22	4.71	8.89	7.25	6.95	2.11	30.30

2 Results

After the calibration, the measurement system presented a maximum uncertainty for a coverage factor of 95 ± 0.43 % of the measured signal. Thus, it is expected that the measured value is as reliable as possible when compared to the real strength of the lips.

Figure 12 shows the performance of a measurement. A patient was submitted to an exam in a suitable accommodation. Three measurements were obtained for the patient, as shown in Fig. 13. The patient was subjectively identified as normotensive and showed strength lip average of 19.5, 23.1 and 19.8 N for each measure. The system presents a regular behavior throughout the trial and apparently cannot detect notable points such as maximum force and force decay.

Table 1 shows average force values in the three tests on each subject, the overall average (the average of three tests), the global standard deviation and coefficient of variation of Pearson (CVP) for each participant. It was chosen for statistical analysis, considering the small sample size, since the main objective of this study was to describe the development of the equipment.

3 Conclusions

An automated system to measure and monitor human lips was described and tested. It is believed that the system presents a great value in complementing the clinical diagnosis, in providing data for discussing individual cases with other professionals involved in the therapeutic process, as well as assisting the patient to see the progress of treatment.

It was possible to assess the strength of resistance against lip through quantitative data generated by a prototype that reproduces the clinical evaluations of the strength of human lips currently performed by audiologists, observing a profile of strength with little variation over time measurement and the absence of notable points that can define a single configuration of the curve force × time, such as peak power or burst decay.

The developed measurement system is intended to assist the diagnosis, prognosis and monitoring treatment, not replacing but complementing the role of a speech pathologist professional, and the presented result indicates the potential of the proposed method.

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