EFFECTIVENESS OF AN OBJECTIVE METHOD TO MEASURE TONGUE STRENGTH

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Abstract. *The aim of this investigation is to quantify and to compare the longitudinal forces produced by the tongue of individuals with severe decrease in tongue strength with that of individuals with normal tongue strength, using a device specially developed for this purpose, and to verify if there are typical force ranges for each group. A cross-sectional study was developed with a sample composed by 11 subjects with severe decrease of tongue strength and 11 subjects with normal tongue strength, all with more than 18 years of age, matched for gender, age and body mass index. The subjects were submitted to a clinical examination (qualitative) of the tongue conducted by two examiners and only those participants who obtained the same classification for tongue strength for both examiners were submitted to the quantitative evaluation. Quantitative evaluation of tongue strength was accomplished using an instrument developed by the Engineering Biomechanics Group of UFMG. The instrument is based on the transformation of force into pressure that is electronically acquired by a pressure transducer for a subsequent reconversion in force. T-Student test was used in the analysis of the data. Statistical significance was set to* $P < 0.05$*. The average of maximum forces of the subjects with severe decrease of tongue strength was 3.6±1.8 N and the average of medium forces in the same group was 2.1±1.2 N. The average of maximum and medium forces of the subjects with normal tongue strength was 18.9±8.0 N and 13.1±5.9 N, respectively. It was verified a significant difference between the groups as in maximum force (*$p< 0.001$*) as in the medium force (*$p< 0.001$*). The variables gender, age and body mass index did not present significant relationship with the forces produced by the tongue. The values obtained in the quantitative assessment were compatible with the results of the qualitative assessment. Therefore, it was verified that the instrument is effective to quantify tongue strength of subjects with severe decrease of tongue strength and of those with normal tongue strength. The instrument is also capable to find the strength ranges that characterize each group and to detect the transition between groups.*

Keywords*:* tongue, instrumentation, pressure, biomechanics.

1. INTRODUCTION

The tongue takes part in the functions of mastication, swallowing, suction, breathing and speech articulation. Its correct positioning in the oral cavity enables a proper breathing; in the act of suction, it makes rhythmic and repetitive movements and takes a position that optimizes the required pressure for that task; in mastication, it allows food to be crushed and mixed to saliva; in swallowing, it is responsible for the ejection of food; it allows the production of each phoneme in speech, as well as alters the resonance characteristics of the oral cavity by changing its shape inside the mouth. The tonus and mobility of the tongue are therefore essential for the tongue to perform harmoniously its intricate tasks.

In Speech-language Pathology clinical practice, the tongue strength is evaluated in a subjective (qualitative) way. One of the forms to verify it consists in asking the patient to protrude the tongue against the finger of the professional or against a tongue depressor. This clinical method of force evaluation depends on the experience of the evaluator and is not free from controversy.

Due to the need for an objective and reproducible tongue force evaluation technique, the Biomechanical Engineering group from UFMG has developed a device to measure the longitudinal tongue force based in the transformation of force into pressure (Motta *et al*., 2004).

The objective of this study was quantify and to compare the longitudinal forces produced by the tongue of subjects with severe decrease of tongue strength with that of subjects with normal tongue strength, using the device developed with this purpose. Based on the results, the existence of characteristic force value bands for each clinical diagnostic was investigated.

2. STRENGTH TONGUE MEASUREMENT REVIEW

Several investigators used different methods to evaluate tongue strength.

Some authors measured tongue strength using a force transducer sensitive to direct compression forces welded to a tubular stem through which passed the wires from the load cell to the recording system. The transducer was positioned between the subject's incisor teeth and the subject was requested to bite down on the stem and to press the tongue against the transducer surface as hard as possible (Dworkin, 1980; Dworkin *et al*., 1980a; Dworkin *et al*., 1980b; Hartman *et al*., 1980; Dworkin, Aronson, 1986; Scardella *et al*., 1993).

Robinovitch *et al*. (1991) used a device composed by an aluminum cantilever beam with two active strain gauges mounted on opposite sides at the base of the beam. The beam could be oriented to take readings of upward tongue thrust or it could be rotated 90° to acquire values of right and left lateral tongue thrust. The tongue made contact only with the transducer and the resulting signal was amplified and transmitted to an analog-to-digital converter.

A tongue pressure transducer system consisted of an air filled bulb connected to a pressure transducer and placed against the anterior roof of the mouth was used by several investigators (Robbins *et al*.,1995; Crow, Ship, 1996; Murdoch *et al*., 1998; Solomon *et al*., 2000; Hayashi *et al*., 2002; Clark *et al*., 2003; McAuliffe *et al*., 2005; Yoshida *et al*., 2006; Stierwalt, Youmans, 2007).

Other authors used a force transducer consisted of a machined nylon hand grip and a mouthpiece consisted of a nylon plate behind which was positioned the load cell. Behind the plate, there was a groove in which subjects were asked to rest their incisor teeth in order to steady the transducer. Force was exerted on the plate by the subjects tongue. The transducer was connected to a linear visual scale that display the force. (Mortimore *et al*., 1999; Mortimore *et al*., 2000).

Sha *et al*. (2000) measured protrusive force of genioglossus in different lengths using a device composed by a tube which contained a latex balloon inflated with saline and connected to a pressure transducer. The subjects held the transducer in the mouth by biting down on the tube, with the tip of the tongue on the balloon, and they could increase or decrease the depth of the transducer in the oral cavity modifying the length of the fibers of the muscle.

Maximum force or pressure is the most commonly used parameter in objective tongue measurement experiments (Dworkin, 1980; Dworkin *et al*., 1980a; Dworkin *et al*., 1980b; Hartman *et al*., 1980; Dworkin, Aronson, 1986; Robbins *et al*., 1995; Crow, Ship, 1996; Mortimore, Douglas, 1996; Murdoch *et al*., 1998; Mortimore *et al*., 2000; Sha *et al*., 2000; Weijnem *et al*., 2000; Hayashi *et al*., 2002; Scardella *et al*., 2003; Motta *et al*., 2004; McAuliffe *et al*., 2005; Yoshida *et al*., 2006; Stierwalt, Youmans, 2007). No study in the literature was found in which average tongue force was used as the only parameter to typify tongue strength. Some authors used both parameters for their analyses (Robinovitch *et al*., 1991; Clark *et al*., 2003; Perilo *et al*., 2007) and verified that both maximum forces/pressures and average measures were statistically related to subjective force evaluation, indicating that both were possible valid ways to define tongue strength. An advantage of the maximum force is that it does not have to be calculated, avoiding extra work.

Horizontal direction was the direction of choice for a number of authors (Dworkin, 1980; Dworkin *et al*., 1980a; Dworkin *et al*., 1980b; Hartman *et al*., 1980; Dworkin, Aronson, 1986; Mortimore and Douglas, 1996; Mortimore *et al*., 1999; Mortimore *et al*., 2000; Scardella *et al*., 2003; Motta *et al*., 2004; Perilo *et al*., 2007). Some authors used devices that measured tongue force or pressure in the cranial direction (Robinovitch *et al*., 1991; Robbins *et al*., 1995; Crow and Ship, 1996; Murdoch *et al*., 1998; Sha *et al*., 2000; Solomon *et al*., 2000; Weijnem *et al*., 2000; Hayashi *et al*., 2002;

Clark *et al*., 2003; McAuliffe *et al*., 2005; Yoshida *et al*., 2006; Stierwalt and Youmans, 2007), others measured horizontal forces, but resulting from lateral movements (Dworkin, 1980; Dworkin *et al*., 1980a; Dworkin *et al*., 1980b; Hartman *et al*., 1980; Dworkin, Aronson, 1986), not allowing direct comparisons with the results described here.

Each tongue displacement involves different muscles, extrinsic and/or intrinsic. In the horizontal direction, the movement of tongue protrusion results from a contraction of the genioglossus and intrinsic muscles responsible for to narrow and lengthen the tongue. As the weakening of a specific muscle can affect one direction more than the others, the results can be different for each direction.

3. METHODS

A transversal study was developed at the UFMG Clinics Hospital, after approval from the Ethics Committee from the University. The sample consisted of 22 individuals, all over 18 years of age, 11 with serious tongue force deficit, forming the group of interest, and 11 with normal tongue force as control group, matched by sex, age (±2 years) and body mass index.

The individuals were first underwent to a clinical miofunctional orofacial evaluation for force, mobility, usual observed posture (as described by the patient), as well as lingual frenulus characteristics. The evaluation was performed by two individuals; one being a professor in Speech-language Pathology specialized in orofacial myology disorders, the other an undergraduate student. Weight and height were measured to obtain the body mass index. Only individuals that had two independent identical classifications by the evaluators were included in the group.

The measurements of tongue force were obtained using a device developed by the Engineering Biomechanics Group, Fig 1a, composed of researchers from UFMG and CETEC (the Technological Center for the state of Minas Gerais), and described by Motta and co-workers (2004). The device is composed of a piston/cylinder assembly attached to a double silicone protector (like that used by the boxers) and to a head that connects it to the cylinder, which hydraulically transmits the produced force to a pressure sensor. The pressure sensor measurements are transmitted through a data acquisition device to a personal computer.

Before the test, the oral silicone protector was fully covered with a transparent non toxic PVC film (Doctor Film) so as to improve and facilitate hygiene. The film was removed immediately after each test and the device disinfected with alcohol 70%.

For each test the oral protector was inserted and fitted in the mouth of the patient, Fig 1b, who had 15 seconds for accommodation. After this period, the patient was required to push the cylinder head with the tongue with the maximum force they could exert, holding it for 10 seconds. This procedure was repeated three times, with one minute intervals and an oral reinforcement at each repetition.

(a) (b)

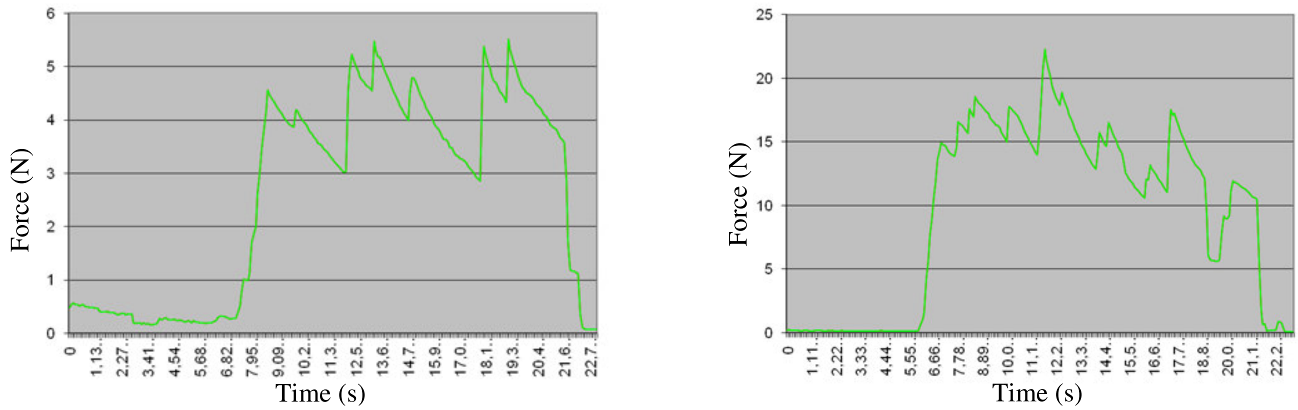
Figure 1 – (a) A general view of developed measurement system. (b) Device application example in clinical assessment.

The exerted tongue force for the individual was converted into pressure by the piston/cylinder assembly. Pressure was used to calculate the exerted force at the personal computer, after the data acquisition, using Eq. (1), where F denote force in Newtons, P is pressure in Pascal and S is area in square meters.

$$F = P \, x \, S \quad (1)$$

During the force application, the computer registered the complete force time history, referenced to the beginning of the test, Fig (2).

For each individual maximum and average forces were calculated. Average force was defined as the average of the force signal throughout the test, and maximum force as the peak force in the considered time interval. The average and maximum forces obtained by normal and severely impaired patients were then compared. T-student tests with 5% significance level were then applied to the obtained data.



(a) (b)

Figure 2 – Force time history graph of an individual with serious tongue force deficit (a) and an individual with normal tongue force (b). Force, in Newtons is in the vertical axis and time, in seconds, in horizontal axis.

4. RESULTS

Tables 1 and 2 show maximum and average forces, as well as the results of the clinical evaluations for each individual.

The analysis showed that the groups had significant difference in average as well as maximum forces. Maximum and average force values for the group of study and control group are given in Tab 3 and Fig 2.

Table 1. Measured force values and results for clinical evaluation for the group of study.

Subject	1	2	3	4	5	6	7	8	9	10	11
Sex	Male	Male	Male	Female	Male	Female	Male	Male	Male	Female	Female
Age (yrs)	78	54	47	88	73	19	71	80	83	45	26
Posture	Tooth sup(10)	Alveolus inf(13)	Alveolus sup(12)	Tooth sup	Tooth inf(11)	Between teeth	Alveolus inf	Alveolus sup	Tooth inf	Tooth inf	Tooth inf
Mobility	Altered	Altered	Normal	Normal	Normal	Normal	Altered	Normal	Altered	Altered	Altered
Aspect	Unaltered	Altered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Enlarged	Enlarged	Unaltered
Frenulus	Normal	Absent	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
BMI(1)	Healthy	Healthy	Overweight	Healthy	Healthy	Low	Low	Healthy	Healthy	Overweight	Healthy
F_{max1} (2) (N)	5.17	5.46	3.97	4.10	2.18	5.51	1.02	1.22	1.75	1.98	5.83
F_{max2} (3) (N)	4.35	5.69	4.95	4.69	2.60	6.60	1.30	2.60	1.75	2.12	4.96
F_{max3} (4) (N)	4.96	5.61	4.69	3.01	3.21	4.71	0.77	0.95	2.10	1.80	5.71
$AvgF_{max}$ (5) (N)	4.83±0.43	5.59±0.12	4.54±0.51	3.93±0.85	2.66±0.52	5.61±0.95	1.03±0.26	1.59±0.88	1.87±0.20	1.97±0.16	5.50±0.47
F_{avg1} (6) (N)	2.97±0.71	3.29±1.25	2.20±0.82	2.11±1.06	1.12±0.68	4.15±0.64	0.51±0.19	0.60±0.29	1.14±0.27	1.17±0.43	3.96±0.88
F_{avg2} (7) (N)	2.93±0.74	3.24±1.43	2.04±1.29	2.57±1.23	1.42±0.56	4.04±1.07	0.88±0.28	1.02±0.64	0.92±0.31	1.14±0.55	3.71±0.56
Fa_{vg3} (8) (N)	2.30±1.20	2.83±1.26	3.04±0.96	1.96±0.44	1.59±0.75	3.50±0.49	0.55±0.11	0.50±0.15	1.38±0.48	0.68±0.40	3.37±1.2
$AvgF_{avg}$ (9) (N)	2.73±0.38	3.12±0.25	2.43±0.54	2.21±0.32	1.38±0.24	3.90±0.35	0.65±0.20	0.71±0.28	1.15±0.23	1.00±0.27	3.68±0.30

(1)BMI = body mass index
(2)F_{max1} = maximum generated force in first measure
(3)F_{max2} = maximum generated force in second measure
(4)F_{max3}= maximum generated force in third measure
(5)$AvgF_{max}$ = average of the maximum forces
(6)F_{avg1} = average generated force in first measure
(7)F_{avg2} = average generated force in second measure
(8)F_{avg3} = average generated force in third measure
(9)$AvgF_{avg}$ = average of the average forces
(10)Tooth sup = at upper teeth
(11)Tooth inf = at lower teeth
(12)Alveolus sup = at upper alveolar region
(13)Alveolus inf = at lower alveolar region

Table 2. Measured force values and results for clinical evaluation for the control group.

Subject	1	2	3	4	5	6	7	8	9	10	11
Sex	Male	Male	Male	Female	Male	Female	Male	Male	Male	Female	Female
Age (yrs)	76	53	47	87	73	19	70	79	84	44	24
Posture	Alveolus inf	Alveolus sup	Entre dent	Tooth inf	Tooth inf	Alveolus sup	Alveolus sup	Alveolus sup	Alveolus sup	Alveolus sup	Alveolus sup
Mobility	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Aspect	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered	Unaltered
Frenulus	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
BMI(1)	Healthy	Healthy	Overweight	Healthy	Healthy	Low	Low	Healthy	Healthy	Overweight	Healthy
F_{max1}(2) (N)	11.22	29.66	21.68	6.74	31.79	22.29	12.10	7.31N	19.61	20.65	26.37N
F_{max2}(3) (N)	13.37	30.61	19.21	7.01	28.86	18.63	13.90	10.50N	22.17	17.02	31.55N
F_{max3}(4) (N)	10.76	23.69	18.23	5.59	28.20	20.96	12.63	13.14N	26.33	13.75	28.35N
$AvgF_{max}$(5)(N)	11.78±1.39	27.99±3.75	19.71±1.78	6.45±0.75	29.62±1.91	20.63±1.85	12.88±0.92	10.31±2.92	22.70±3.39	17.14±3.45	28.76±2.61
F_{avg1}(6) (N)	8.33±1.55	22.96±3.20	16.37±2.60	5.04±1.05	24.28±4.45	14.29±3.23	7.75±1.86	3.86±1.36	14.17±2.69	12.11±3.02	17.87±2.57
F_{avg2}(7) (N)	7.92±2.39	20.84±4.04	14.22±2.20	4.61±0.88	18.64±5.15	14.29±2.22	10.47±1.76	6.13±2.11	14.04±3.02	11.90±1.99	20.83±4.14
Fa_{vg3}(8) (N)	7.23±1.24	17.19±3.08	14.74±2.06	4.00±0.59	21.76±3.16	15.03±2.40	10.37±1.33	5.18±3.37	18.49±3.20	9.34±1.7	17.40±4.29
$AvgF_{avg}$(9)(N)	7.83±0.55	20.33±2.92	15.11±1.12	4.55±0.52	21.56±2.82	14.54±0.43	9.53±1.54	5.06±1.14	15.57±2.53	11.12±1.54	18.7±1.86

(1)BMI = body mass index
(2)F_{max1} = maximum generated force in first measure
(3)F_{max2} = maximum generated force in second measure
(4)F_{max3}= maximum generated force in third measure
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(6)F_{avg1} = average generated force in first measure
(7)F_{avg2} = average generated force in second measure
(8)F_{avg3} = average generated force in third measure
(9) $AvgF_{avg}$ = average of the average forces
(10)Tooth sup = at upper teeth
(11)Tooth inf = at lower teeth
(12)Alveolus sup = at upper alveolar region
(13)Alveolus inf = at lower alveolar region

Table 3. Average and maximum forces in Newtons for control and study groups.

	Group of study	Control group	p-value
Maximum force	3.56±1.77 N	18.91±7.95 N	< 0.001
Average force	2.09±1.18 N	13.08±5.91 N	< 0.001

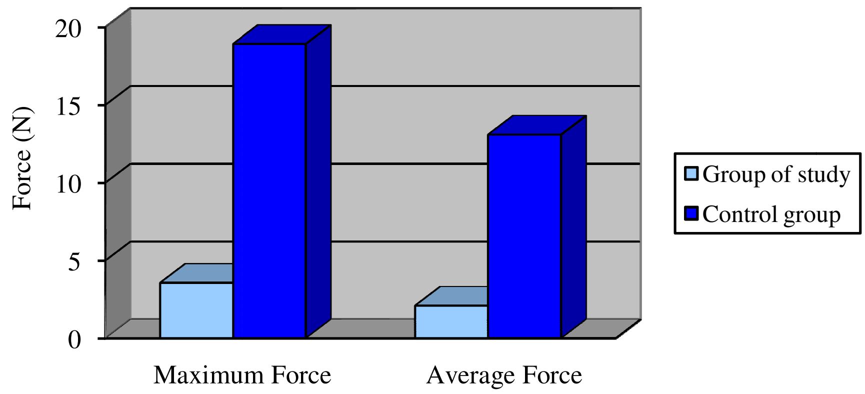

Figure 3 – Average and maximum force distribution in Newtons for study and control groups.

The variables sex (Tab 4), age (Tab 5) and corporal mass index (Tab 6, 7, 8) did not show significant relationship with the tongue force.

Table 4. Average of maximum and average forces in Newtons by sex.

	Group of study			Control group		
Sex	Male	Female	p-value	Male	Female	p-value
(1)F_{max}	3.16±1.80 N	4.25±1.70 N	0.355	19.28±7.88 N	18.24±9.25 N	0.858
(2)F_{avg}	1.74±1.00 N	2.70±1.36 N	0.285	13.57±6.29 N	12.23±5.98 N	0.737

(1)F_{max} - Maximum force
(2)F_{avg} - Average force

Table 5. Average of maximum and average forces in Newtons by age.

	Group of study			Control group		
Age	Adults	Elderly	p-value	Adults	Elderly	p-value
F_{max}	4.64±1.56 N	2.65±1.47 N	0.062	22.84±5.21 N	15.62±8.72 N	0.128
F_{avg}	2.83±1.17 N	1.47±0.84 N	0.067	15.96±3.63 N	10.68±6.65 N	0.139

Table 6. Average of maximum and average forces in Newtons by body mass index.

	Group of study			Control group		
BMI(1)	Low weight	Healthy	Overweight	Low weight	Healthy	Overweight
F_{max}	3.32±3.24	3.71±1.68	3.25±1.81	16.75±5.48	19.66±9.87	18.42±1.82
F_{avg}	2.27±2.30	2.14±1.10	1.71±1.01	12.03±3.54	13.37±7.37	13.11±2.82

(1) BMI = body mass index

Table 7. Comparison of maximum force values in the group of study according to body mass index.

	Low weight	Healthy	Overweight
Low weight	-	p=0.896	p=0.984
Healthy	p=0.896	-	p=0.804
Overweight	p=0.984	p=0.804	-

Table 8. Comparison of maximum force values in the control group according to body mass index.

	Low weight	Healthy	Overweight
Low weight	-	p=0.765	p=0.753
Healthy	p=0.765	-	p=0.765
Overweight	p=0.753	p=0.765	-

5. DISCUSSION

In this study, maximum and average tongue force values were obtained and analyzed for 22 individuals.

The sample used in this study had a wide variation in age, with individuals ranging from 19 to 89 years of age and an average of 60.36. Similar age profile was used in other studies (Crow, Ship, 1996; Clark *et al.*, 2003; Stierwalt, Youmans, 2007). The use of a wide variation in age results from the difficulty in finding patients with severe impairment of tongue force, and a stricter requirement in terms of age would result in a reduction of the sample.

The methodological differences made it difficult to compare tongue forces measured in different studies, as it depends of a number of factors such as the degree of protrusion, the direction of the movement, the distance between mandible and maxilla, the tongue region in contact with the sensor, the area in which the pressure is exerted. A lack of reproducibility in any of these parameters might lead to significant variation in the obtained results.

It was verified in this study that maximum force values were considerably higher in individuals classified as having normal force in the clinical evaluation when compared to severe tongue force impairment. The significant difference observed between the two groups agrees with the findings of Clark and coworkers, who compared tongue force values of normal individuals with others with severe tongue hypotension (Clark *et al.*, 2003). Robinovitch and his group also showed the possibility to detect the difference between tongue force in dysphasic and individuals without problems in swallowing (Robinovitch *et al.*, 1991). Other studies showed a similar correlation when comparing maximum force or pressure in normal individuals with patients with severe tongue impairment (Clark *et al.*, 2003), or with disartric individuals (Dworkin *et al.*, 1980a; Dworkin and Aronson, 1986), multiple sclerosis patients (Murdoch *et al.*,1998), dysphasic patients (Robinovitch *et al.*, 1991; Stierwalt, Youmans, 2007) or bulbar myasthenia gravis patients (Weijnen *et al.*, 2000).

There was not an important difference in medium or maximum force in the objective evaluation between gender, neither in the control nor the interest groups. The information found in the literature is not conclusive, but this finding agrees with the works published by some authors (Hayashi *et al.*, 2002; Clark *et al.*, 2003; McAuliffe *et al.*, 2005; Yoshida *et al.*, 2006). Other researchers described in their results lower maximum tongue forces for healthy women than for men (Dworkin *et al.*, 1980a; Dworkin, Aronson, 1986; Crow and Ship, 1996; Mortimore *et al.*, 1999; Stierwalt and Youmans, 2007). These findings could be related to the fact that men tend to have a higher body mass index. Mortimore and his group showed that, when considering body mass index, there was no significant difference in maximum tongue force for men and women (Mortimore *et al.*, 1999).

To verify the effect of age in tongue force the sample was divided in adults (below 60 years of age) and elderly (above 60). The bound between the groups was taken as 60 due to the fact that, at this age, the individuals tend to lose muscular mass and to suffer motor neurons lost and atrophy.

No significant difference was found between adults and elder individuals, in none of the two groups (control and group of interest), which confirmed the findings of other studies (Dworkin *et al*., 1980a; Dworkin *et al*., 1980b; Hartman *et al*., 1980; Stierwalt, Youmans, 2007). Nevertheless, lower medium values were found for elders and for adults, with p-values in the group of study close to the established level. Other studies with healthy individuals, with larger samples, found lower values for elders (Crow, Ship, 1996; Mortimore *et al*., 1999; Mortimore *et al*., 2000; Hayashi *et al*., 2002; Clark *et al*., 2003).

No correlation was found between body mass index and maximum tongue force. Some authors report a significant inverse correlation between maximum force or pressure and BMI (Mortimore *et al*., 2000; Yoshida *et al*., 2006). As these studies used a large sample, it is possible that a different result might be found with a larger sample.

The device was appropriate to reproduce the clinical evaluation and to separate individuals with normal and hypotension. A limitation of this study was the size of the sample. The test duration should not be shorter than seven seconds as, even though normal individuals produce maximum force in the first seconds, patients with severe decrease of tongue strength need this time to reach peak force values (Dworkin *et al*., 1980a). Only one patient, with Parkinson´s Disease, was not capable of sustaining the force for ten seconds in none of the three tests. Studies described in the literature, discussing the maintenance of 50% of the peak force for a prolonged period of time, verified a high level of fatigue in tongue muscles for Parkinson´s Disease patients, which matches the observed fact (Solomon *et al*., 2000; McAuliffe *et al*., 2005).

6. CONCLUSION

As the obtained subjective and measured results coincide in detecting severe tongue impairment, they demonstrate the capability of the device used in this work to classify individuals in these two groups. The use of this kind of tool can help in the evaluation of orofacial myology by allowing diagnosing speech-language pathology problems and also in the follow up of these patients. The speech-language pathology can dispose of force values and follow its progress as a result of treatment, as well as its decrease in case of degenerative diseases. Even though the quantitative data show that, for a trained specialist, the difference between a healthy individual and another with serious force impairment can be easily detected by clinical evaluation, minor changes occurring during the treatment are hard to perceive. In this case an objective measure of the tongue force can be use to assess clinical progress.

The tests provided numerical values for maximum and average tongue forces for normal and severely impaired cases, showing a significant difference between the two. This can lead to the establishment of bounds of normality for tongue force, and to perceive the transition between the two situations.

The authors suggest that a new study with a larger sample be performed for severely impaired patients, also testing the effect of rest and test time on the results. Another aspect to be studied is the endurance of the tongue of severely impaired patients. Another point to be exploited is the use of visual feedback by letting the patient follow the force x time graph (Hartman *et al*., 1980; Robinovitch *et al*., 1991; Robbins *et al*., 1995; Crow, Ship, 1996; Mortimore *et al*., 2000).

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